

**An Artificial Intelligence Approach to Establishing Critical Factors Influencing Offsite
Construction Adoption in The United Kingdom**

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Abstract

Offsite Construction (OSC) is a construction prefabrication concept that is being rejuvenated. Scholars have evaluated factors affecting the wider uptake of the re-introduced product, but adoption challenges persist despite acclaimed benefits. Faced with increasing housing deficit, environmental sustainability and the ambitious 2050 net-zero target, the United Kingdom (UK) government eagerly seeks ways to solve the OSC adoption puzzle because of its potential in addressing these challenges or stop further investment of tax-payers money in OSC innovation as some UK Parliament members suggested. This study, therefore, took a more rigorous approach to evaluating the factors influencing OSC adoption in the UK, relying on a mixed method approach. It aims to establish the critical OSC adoption influencing factors in the United Kingdom and to develop a predictive model using machine learning techniques for predicting adoption likelihood based on the identified critical factors.

This study appraised existing OSC factors through extant literature using systematic literature reviews (SLRs). The first review explored the various factors influencing OSC globally. The second review highlighted analytical approaches used to identify the factors influencing OSC adoption and the theoretical approach used to address the article's research aim. The third review evaluated the state of OSC development in the UK through the lens of the Royal Institute of British Architects Plan of Work (RIBA-PoW). The study was hinged on three theoretical underpinnings, namely the Concern-Based Adoption Model, ADKAR change model and the RIBA-PoW.

Employing pragmatism as its philosophical stance and using a mixed method research approach, findings from the first SLR were used to interviews twelve UK construction industry (UKCI) professionals. The SLRs and interview data were analysed using content and thematic analyses, including appraising the findings under the lens of RIBA-PoW. The study triangulated findings from SLR 3 and interview analysis to develop a survey questionnaire used to quantitatively evaluate OSC influencing factors identified. The survey targeted 500 responses; however, 337 responses were received. 315 responses from the 337 were valid for quantitative analysis and predictive model development.

The quantitative approach used exploratory analysis in setting the tone, before conducting a correlation analysis to drop features with multicollinearity effect on the data. Employing multi-class classification and binary classification and using 10 feature selection methods, the analysis identified eight very critical factors that show tendencies to influence OSC adoption significantly. They are Awareness of Planning Authority officials (AW4), Design lead time-the amount of time required before freezing OSC design (DCF1), Scalability- Repeatability of design and project modules (DCF10) Availability of past OSC project data to support use of OSC for proposed projects (PKD2), Monotonous perception about OSC designs (PP5), Road width that fits OSC delivery trucks (SCL7), Access Road to the site that fits truck size (SCL8) and Site Hedging (SCL11) . The study developed an adoption model for possible prediction of OSC adoption in the UK following exploratory data analysis and feature selection done. Logistic Regression, LR, (Random State 42) employing Mode imputation for Significant features, in a multi-class experiment using a splitting ratio 80:20, having an accuracy score of 85.71% emerged as the best predictive model, displaying no form of overfitting across all ML development measures.

The research contributed to theory, practise and policy. The study advances theory by providing a structured interpretive lens to understand behavioural and organisational readiness that can redefine the approach to unearthing OSC adoption issues beyond what extant literatures present. Additionally, the study adopted methodological and analytical pluralism, integrating literature synthesis, qualitative triangulation, and ML-based predictive modelling -a rare but powerful analytical combination in OSC adoption studies. Further, the study extended ADKAR model to $ADKAR \Rightarrow A$. By extending ADKAR model to $ADKAR \Rightarrow A$, the study argued that showcasing successful OSC projects creates awareness (A)— a means to increasing OSC knowledge and consequently, potential adoption.

Practical-wise, the study developed a framework for aggregating OSC project data for OSC adoption prediction in the UK- a template that can be adopted globally. The ML model developed is the first OSC adoption predictive model for the pursuit of wider OSC adoption in the UK- a model that provides significant generalisable and explainable AI approach to OSC adoption, irrespective of the category or type of OSC, if well implemented. Environmentally, this OSC research findings significantly contribute to cleaner construction production and environment, and they promote Sustainable Development Goals (SDGs) 9, 11 and 13 in pursuit of a net-zero carbon target.

Policy-wise, the study's findings illuminate infrastructural, behavioural, technical, and policy-levels levers that can be targeted to boost OSC uptake. The study approach and finding offers the formulation of targeted adoption strategies for academics, industry stakeholders and policymakers and focal points for interventions. The findings also provide better theoretical understanding of OSC adoption factors to help UKCI concert adoption pursuit efforts rightly and the government, to appropriate more pragmatic policies in achieving the targeted 25% OSC usage in construction projects.

Keywords: Adoption, Adoption Theories, Artificial Intelligence, Buildings, Change Management, Construction, Critical Factors, Machine Learning, Modern Methods of Construction, Offsite Construction, United Kingdom.

Declaration

This doctoral thesis is the result of my research. It is not substantially the same as any that has been previously written or submitted or is being simultaneously submitted for a degree or other qualification at the University of Hertfordshire or any other University or similar institution.

Dedication

This work is dedicated to God Almighty, the Maker of heavens and earth, and to the blessed memory of my mother, Yemisi Ibironke Wusu, whose motherhood style, sacrifices and dedication to child upbringing was very inspiring.

I also dedicate this work to the memories of my Sunday School Teacher, Pa. E A Koshodo, and my bishop, the Rt Rev S G Kuponu.

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Research Outputs

Published Journal Articles from thesis.

1. **Wusu, G.**, Alaka, H., Oseghale, R., Yusuf, W., Sunmola, F., Ajayi, S., & Alrashoud, M. (2025). A qualitative assessment of offsite construction awareness in the United Kingdom: Construction industry experts' view. *Building Research Information*. <https://researchprofiles.herts.ac.uk/en/publications/a-qualitative-assessment-of-offsite-construction-awareness-in-the-united-kingdom> DOI - 10.1080/09613218.2025.249873

Other Published Journal Articles

1. Balogun, H., Alaka, H., Demir, E., Egwim, C. N., **Wusu, G. E.**, Yusuf, W., Adegoke, M., & Qasim, I. (2025). Deconstructability prediction for building using machine learning and ensemble feature selection techniques. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-00790-0>
2. Egwim, C. N., Hafiz Alaka, Demir, E., Balogun, H., Olu-Ajayi, R., Sulaimon, I., **Wusu, G.**, Yusuf, W., & Muideen, A. A. (2023). Artificial Intelligence in the Construction Industry: A Systematic Review of the Entire Construction Value Chain Lifecycle. *Energies*, 17(1), Article 1. <https://doi.org/10.3390/en17010182>
3. Olu-Ajayi, R., Alaka, H., Sulaimon, I., Balogun, H., **Wusu, G.**, Yusuf, W., & Adegoke, M. (2023b). Building energy performance prediction: A reliability analysis and evaluation of feature selection methods. *Expert Systems with Applications*, 225, 120109. <https://doi.org/10.1016/j.eswa.2023.120109>
4. **Wusu, G.**, Alaka, H., Yusuf, W., Mporas, I., Toriola-Coker, L., & Oseghale, R. (2022). A machine learning approach for predicting critical factors determining adoption of offsite construction in Nigeria. *Smart and Sustainable Built Environment, ahead-of-print*(ahead-of-print). <https://doi.org/10.1108/SASBE-06-2022-0113>

Conference Articles from thesis

1. **Wusu, G.**, Alaka, H., Oseghale, R., Balogun, H., Sunmonu, F., & Ajayi, S. (2025). A Qualitative Evaluation Human Behaviour Issues Influencing Wider Offsite Construction Adoption in the United Kingdom. *Proceedings of the International Conference on Smart and Sustainable Built Environment (SASBE 2024)* (pp. 124–134). Springer Nature. https://doi.org/10.1007/978-981-96-4051-5_13
2. **Wusu, G.**, Alaka, H., Oseghale, R., & Oriowo, O. (2025). A State-of-the-Art Review of Offsite Construction Adoption Within the UK Construction Industry- the RIBA-Plan of Work Perspective. *Proceedings of the International Conference on Smart and Sustainable Built Environment (SASBE 2024)* (pp. 170–179). Springer Nature. https://doi.org/10.1007/978-981-96-4051-5_17
3. **Wusu, G.**, Alaka, H., Oseghale, R., Yusuf, W., Sunmonu, F., Ajayi, S., Oriowo, O., & Akinyemi, B. (2025). Effectively Transiting from Traditional Construction Method to Offsite Construction Through Robust Data Management Repository-Implications to Wider OSC Approach and Adoption. *Proceedings of the International Conference on Smart and*

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4. **Wusu, G.**, Alaka, H., Oseghale, R., Yusuf, W., Sunmonu, F., & Akinyemi, B. (2025). A Qualitative Assessment of Awareness Influencing Factor on Offsite Construction Adoption Within the United Kingdom- A Construction Industry Professionals' View. *Proceedings of the International Conference on Smart and Sustainable Built Environment (SASBE 2024)* (pp. 115–123). Springer Nature. https://doi.org/10.1007/978-981-96-4051-5_12

Other Conference Articles

1. **Wusu, G.**, & Alaka, H. (2021). Art, Aesthetics and Innovations in The Built Environment: Beyond Theory into Practice. *EDMIC 2021 CONFERENCE PROCEEDINGS ENVIRONMENTAL DESIGN & MANAGEMENT INTERNATIONAL CONFERENCE: Confluence of Theory and Practice in the Built Environment: Beyond Theory into Practice*, 88–93. <https://researchprofiles.herts.ac.uk/en/publications/art-aesthetics-and-innovations-in-the-built-environment-beyond-th>
2. **Wusu, G.**, Alaka, H., Ajayi, S., Oseghale, R., & Yusuf, W. (2021). Barriers to Successful Adoption of Design for Manufacture and Assembly in Nigeria. *EDMIC 2021 CONFERENCE PROCEEDINGS ENVIRONMENTAL DESIGN & MANAGEMENT INTERNATIONAL CONFERENCE: Confluence of Theory and Practice in the Built Environment: Beyond Theory into Practice*, 42–53. <https://researchprofiles.herts.ac.uk/en/publications/barriers-to-successful-adoption-of-design-for-manufacture-and-ass>
3. Yusuf, W., Alaka, H., **Ebenezer, W.**, Ajayi, S., & Toriola-Coker, L. O. (2021). Machine Learning Recognition Models in Construction: A Systematic Review. *EDMIC 2021 CONFERENCE PROCEEDINGS ENVIRONMENTAL DESIGN & MANAGEMENT INTERNATIONAL CONFERENCE: Confluence of Theory and Practice in the Built Environment: Beyond Theory into Practice*, 486–497. <https://researchprofiles.herts.ac.uk/en/publications/machine-learning-recognition-models-in-construction-a-systematic->

List of Tables

Table 2.1: Summary of OSC Drivers from Literature Review	52
Table 2.2: Summary of OSC Barriers from Literature Review	59
Table 2.3: Findings from SLR 2	74
Table 2.4: Findings from SLR 3	96
Table 2.5: Analysis of the Reviewed Articles and the Stages of RIBA-PoW discussed.	106
Table 2.6: Summary of RIBA stage of works identified by reviewed articles.	107
Table 5.1: Demography of Interview Respondents	185
Table 5.2: Factor Count and Industry Number Report identified by respondents.	188
Table 5.3: Summary of interview content analysis (Coding Register)	191
Table 5. 4: Summary of qualitative findings and relevant quotes from textual Analysis for themes	198
Table 6.1: Construct Variables Tagging.	223
Table 6.2: Summary of Cronbach Alpha Reliability Report for each Construct	237
Table 6.3: Variable Significance according to Chi-Square Test	243
Table 7.1: Dropped Features and Retained Features (A case of Multi-Class Classification using Mode Imputation)	253
Table 7.2: Selected Features after Handling Multicollinearity	254
Table 7.3: Feature Selection (FS) Method Categorization	263
Table 7.3: Top 25 features selected from each FS Method (A case of MCC using Mode missing data imputation)	265
Table 7.5: Multi-Class Classification Feature Selection List	267
Table 7.6: Binary Classification Feature Selection List	268
Table 8.1: DVMain Class distribution before and after resampling	275
Table 9.1: Comparison of Factors with very high likelihood OSC adoption influence in the UK according to Multi-Class Classification with SLR and Qualitative Analysis	298
Table 9.2: Comparison of Factors with high criticality OSC adoption influence in the UK according to Binary Classification with SLR and Qualitative Analysis	299
Table 9.3a: Machine Learning Results for Random State (42)	302
Table 9.3b: Machine Learning Results for Random State (45)	303
Table 9.3c: Machine Learning Results for Random State (50)	304
Table 9.3d: Machine Learning Results for Random State (55)	305
Table 9.3e: Machine Learning Results for Random State (60)	306
Table 9.3f: Machine Learning Results for Random State (65)	307
Table 9.3g: Machine Learning Results for Random State (70)	308
Table 9.3h: Machine Learning Results for Random State (75)	309
Table 9.3i: Machine Learning Results for Random State (80)	310
Table 9.3j: Machine Learning Best Results Table for Random State (42-80) Iterations	311
Table 9.4a: Detailed Performance of models with high Accuracy (Multi-Classification, Mode Imputation, Splitting Ratio 80: 20)	316
Table 9.4b: Detailed Performance of models with high AUC performance	

(Multi-Classification, Mode Imputation, Splitting Ratio 80: 20)	316
Table 9.4c: Detailed Performance of models with high accuracy (Multi-Classification, Mode Imputation, Splitting Ratio 70:15:15)	316
Table 9.4d: Detailed Performance of models with high AUC performance (Multi-Classification, Mode Imputation, Splitting Ratio 70:15:15)	316
Table 9.4e: Detailed Performance of models with high Accuracy (Multi-Classification, KNN Imputation, Splitting Ratio 80: 20)	317
Table 9.4f: Detailed Performance of models with high AUC performance (Multi-Classification, KNN Imputation, Splitting Ratio 80: 20)	317
Table 9.4g: Detailed Performance of models with high accuracy (Multi-Classification, KNN Imputation, Splitting Ratio 70:15:15)	317
Table 9.4h: Detailed Performance of models with high AUC performance (Multi-Classification, KNN Imputation, Splitting Ratio 70:15:15)	317
Table 9.5a: Detailed Performance of models with high accuracy result (Binary Classification, Mode Imputation, Splitting Ratio 80:20)	318
Table 9.5b: Detailed Performance of models with high AUC performance (Binary Classification, Mode Imputation, Splitting Ratio 80:20)	318
Table 9.5c: Detailed Performance of models with high accuracy result (Binary Classification, Mode Imputation, Splitting Ratio 70:15:15)	318
Table 9.5d: Detailed Performance of models with high AUC performance (Binary Classification, Mode Imputation, Splitting Ratio 70:15:15)	318
Table 9.5e: Detailed Performance of models with high accuracy result (Binary Classification, KNN Imputation, Splitting Ratio 80:20)	319
Table 9.5f: Detailed Performance of models with high AUC performance (Binary Classification, KNN Imputation, Splitting Ratio 80:20)	319
Table 9.5g: Detailed Performance of models with high accuracy (Binary Classification, KNN Imputation, Splitting Ratio 70:15:15)	319
Table 9.5h: Detailed Performance of models with high AUC performance (Binary Classification, KNN Imputation, Splitting Ratio 70:15:15)	319

List of Figures

Figure 1.0: Thesis Outline	27
Figure 2.1.1: SLR Documents by publication year	46
Figure 2.1.2: SLR Documents by geographical location	46
Figure 2.1.3: SLR Documents by subject area	47
Figure 2.1.4: Systematic Literature Review Process Flow Chart	48
Figure 2.1.5: Count of reviewed articles	50
Figure 2.1.6: SLR Notion of Themes	51
Figure 2.1.7: Influence of Identified themes on OSC adoption according to SLR 1	67
Figure 2.1.8: Conceptual Framework to Approaching OSC influencing factors.	70
Figure 2.2.1: Research Approaches Used according to Reviewed Articles	73
Figure 2.2.2: RIBA-PoW stages Explored according to reviewed articles	81
Figure 2.2.3: Articles Theory Count	82
Figure 2.2.4: Theory/Model Development Count	83
Figure 2.3.1: RIBA POW overlaid with DfMA PoW	88
Figure 2.3.2: RIBA-PoW Stages overlaid with OSC Stages Works	89
Figure 2.3.3a: SLR Documents by publication year	91
Figure 2.3.3b: SLR Documents by subject area	91
Figure 2.3.4: Systematic Literature Review Process Flow Chart	92
Figure 3.1: Concern Based Adoption Theory	121
Figure 3.2: ADKAR Change Model	123
Figure 3.3: A theoretical Framework for Wider OSC adoption from a theory perspective	125
Figure 4.1: Research Diagram	129
Figure 4.2: Research Methodology	141
Figure 4.3: Survey Questionnaire Development	158
Figure 5.1: Industry experience of interview respondents	187
Figure 5.2: Qualitative Interview Analysis	193
Figure 5.3: Interview Content Analysis	194
Figure 5.4: Weight of factors identified from interview analysis.	197
Figure 6.1: Quantitative Analysis Approach	229
Figure 6.2a: Consent to taking the survey.	231
Figure 6.2b: Number of respondents who ever worked on or have been involved in any project(s) in the UK where Offsite Construction (OSC) was/is used for the project or where a part of the project(s) was/is OSC.	232
Figure 6.2c: Number of respondents who considered OSC for their projects or not	232
Figure 6.2d: Respondents' specialization.	233
Figure 6.2e: Respondents' education qualification.	234
Figure 6.2f: Number of years respondents have been in construction-related practice	234
Figure 6.2g: Years of construction(related) practice involving the design or/and construction of OSC project.	235
Figure 6.2h: Number of OSC projects respondents worked on, including any current one	235
Figure 6.2i: Location of OSC projects respondents worked on.	236

Figure 6.3: Plot of Mode Values	243
Figures 6.4 (a-d): Exploring the distribution of some of the categorical variables.	244
Figure 6.5: Visualizing the distribution of ordinal variables using histograms. (A case of MCC Mode Imputation).	245
Figure 6.6: A graphical count of missing values from the survey response	247
Figure 6.7: Significant variables according to Chi-Square Test	259
Figure 7.1a: Visualisation of Correlation Analysis Heatmap (The Mode Imputation Instance for Multi-Class Classification)	265
Figure 7.1b: Visualisation of Correlation Analysis Dendrogram (The Mode Imputation Instance for Multi-Class Classification)	266
Figure 7.2: Quantitative Analysis/ Feature Selection Framework	272
Figure 8.1: Model Development Architecture	288
Figure 8.2 (a & b): Stratified Cross-Validation and Cross-Validation description	297
Figure 9.1: Possible approach to addressing OSC data collection.	348
Figure 10.1: Extended ADKAR Model	360

List of Abbreviations

ACSE	-	American Society of Civil Engineers
ADKAR	-	Awareness, Desire, Knowledge, Ability, Reinforcement
AECO	-	Architecture, Engineering, Construction, and Operations
AI	-	Artificial Intelligence
AHP	-	Analytical Hierarchy Process
ANOVA	-	Analysis of Variance
AUC	-	Area Under the Curve
AUC-ROC	-	Area Under the Curve of Receiver's Operating Characteristics
AW	-	Awareness Factor
BC	-	Binary Classification
BBNN	-	Backward Feed Neural Network
BIM	-	Building Information Modelling
BSH	-	Buffer space hedging
CBAM	-	Concerns-Based Adoption Model
CITB	-	Construction Industry Training Board
CEM	-	Construction, Engineering and Management
CI	-	Construction Industry
CIC	-	Construction Industry Council
CMC	-	Construction Market and Cost
CV	-	Cross Validation
DCF	-	Design and Construction Factors
DfM	-	Design for Manufacture
DfA	-	Design for Assembly
DfMA	-	Design for Manufacture and Assembly
DMF	-	Decision Making Factors
DOI	-	Diffusion of Innovations
DQ	-	Data quality
DSS	-	Decision Support System
DVMain	-	Dependent Variable
DT	-	Decision Tree
ECC	-	Expert choice comparison
ET	-	ExtraTrees

FFNN	-	Forward Feed Neural Network
FN	-	False Negative
FP	-	False Positive
FS	-	Feature Selection
GB	-	GradientBoosting
GI	-	General Information
GS	-	Google Scholar
GBC UK	-	Green Building Council, United Kingdom
HVAC	-	Heating, Ventilation and Air Conditioning
IBS	-	Industrial Building System
IDCV	-	Instrument Development and Construct Validation
IDT	-	Innovation Diffusion Theory
IEEE	-	Institute of Electrical and Electronics Engineering
IHS	-	Industrialized housing systems
IPR	-	Interview Protocol Refinement
IoT	-	Internet of Things
IPA	-	Infrastructure and Projects Authority
JISC	-	Joint Information Systems Committee
JIT	-	Just-in-Time
LR	-	Logistics Regression
KN	-	KNeighbours
KNN	-	K-Nearest Neighbour
MCC	-	Multi-Class Classification
MDSS	-	Multi-Criteria Decision Support System
MEP	-	Mechanical, Electrical and Plumbing
MC	-	Modular Construction
MiC	-	Modular Integrated Design
ML	-	Machine Learning
MLP	-	Multi-Layer Perceptron
MMC	-	Modern Methods of Construction
MS	-	Microsoft
MtA	-	Manufacturing, Transportation and Assembly
MTMM	-	Multitrait-Multimethod Matrix

M&E	-	Mechanical and Electrical
ME	-	Margin of Error
NFL	-	No Free Lunch (Theorem)
NPT	-	Normalisation Process Theory
OLR	-	Ordinal Logistics Regression with Recursive Feature Elimination
OSC	-	Offsite Construction
ONS	-	Office of National Statistics
PA	-	Project Attitude
PCA	-	Principal Component Analysis
PD	-	Project Details
PESTEL	-	Political, Economic, Social, Technical, Environmental and Technical
PRISMA	-	Preferred Reporting Items for Systematic and Meta Analysis
PD	-	Pod Construction
PKD	-	Project Knowledge and Data
PP	-	Perception Issues
PPVC	-	Pre-manufactured Pre-finished Volumetric Construction
PCSCM	-	Prefabricated Construction Supply Chain Management
PLS-SEM	-	Partial Least Square Structural Equation Modelling
POI	-	Phenomenon of interest (POI)
RAC	-	Recycled Aggregate Concrete
PRS	-	Policy, Regulation and Sustainability
PTM	-	Project Team and Management
RF	-	Random Forest
RFE	-	Recursive Feature Elimination with Logistics Regression
RFID	-	Radio Frequency Identifying Device
RIBA	-	Royal Institute of British Architects
RIBA-PoW	-	Royal Institute of British Architects Plan of Works
ROC	-	Receiver's Operating Characteristics
ROI	-	Return on Investments
RS	-	Random State
QRCode	-	Quick Response Code
SCM	-	Supply Chain Management
SEM	-	Structural Equation Modelling

SCL	-	Supply Chain and Logistics
SLR	-	Systematic Literature Review
SME	-	Small and Medium Enterprises
SMOTE	-	Synthetic Minority Over-Sampling Technique
SSAH ECDA	-	Social Sciences, Arts and Humanities Ethics Committee with Delegated Authority
SVC	-	Support Vector Classifier
SWOT	-	Strength, Weakness, Opportunities and Threats
TAM	-	Technology Acceptance Model
TELOSS	-	Technical, Economic, Legal, Operational, Schedule and Social
TIP	-	Transforming Infrastructure Performance
TN	-	True Negative
TP	-	True Positive
WWII	-	World War Two
UH	-	University of Hertfordshire
UK	-	United Kingdom
UKCI	-	United Kingdom construction industry
UK-HEA	-	United Kingdom Higher Education Authority
UTAUT	-	United, Theory of Acceptance of Use of Technology

Table of Contents

ABSTRACT	ERROR! BOOKMARK NOT DEFINED.
DECLARATION	III
DEDICATION	IV
ACKNOWLEDGEMENT	V
RESEARCH OUTPUTS	VII
LIST OF TABLES	IX
LIST OF FIGURES	XI
LIST OF ABBREVIATIONS	XIII
TABLE OF CONTENTS	XVII
CHAPTER ONE	1
1.0 INTRODUCTION	1
<i>CHAPTER OVERVIEW</i>	1
1.1 BACKGROUND TO THE STUDY	1
1.2 OSC CONCEPT AND DEFINITION.....	3
1.2.1 The Offsite Construction Concept	3
1.2.2 OSC Definitions.....	4
1.3 OFFSITE CONSTRUCTION IN THE UK.....	6
1.4 PROBLEM STATEMENT	7
1.5 LITERATURE SYNTHESIS AND KNOWLEDGE GAP	9
1.6 KNOWLEDGE GAP.....	11
1.7 JUSTIFICATION FOR THE STUDY	14
1.8 RESEARCH AIM AND OBJECTIVES.....	15
<i>Study Aim</i>	15
<i>Research Objectives</i>	16
1.9 RESEARCH QUESTIONS	16
1.10 RESEARCH METHODOLOGY	17
<i>Philosophical Positioning</i>	17
<i>Theoretical Positioning</i>	18
<i>Research Method</i>	19
1.11 THE MIXED METHOD.....	20
1.12 STUDY CONTRIBUTION	21
1.13 SCOPE AND DELIMITATIONS	23
<i>Scope of the Study</i>	23
<i>Delimitations of the Study</i>	25
1.14 ASSUMPTIONS AND LIMITATIONS	26
<i>Assumptions</i>	26
<i>Limitations</i>	28
1.15 FUTURE STUDIES.....	28
1.16 THESIS OUTLINE	29
CHAPTER SUMMARY	30
CHAPTER TWO	31
2.0 LITERATURE REVIEW	31
<i>CHAPTER OVERVIEW</i>	31

2.1	SYSTEMATIC LITERATURE REVIEW AT A GLANCE	31
2.2	OFFSITE CONSTRUCTION AT A GLANCE	36
2.2.1	OSC Definitions.....	37
2.2.2	Factors influencing OSC Adoption	40
2.3	SYSTEMATIC LITERATURE REVIEW 1: <i>DRIVERS AND BARRIERS INFLUENCING OSC ADOPTION- A GLOBAL REVIEW PERSPECTIVE.</i>	46
2.3.1	Review Approach.....	46
2.3.2	Data sorting, cleaning and review outcomes	53
2.3.3	Drivers of OSC	56
2.3.4	Barriers of OSC.....	62
2.3.5	SLR 1 Summary	72
2.4	SYSTEMATIC LITERATURE REVIEW 2: <i>AN INTEGRATIVE AND GLOBAL REVIEW OF ANALYTICAL METHODS AND THEORETICAL APPROACHES EMPLOYED IN IDENTIFYING CRITICAL OSC INFLUENCING FACTORS.</i>	75
2.4.1	Analytical Approaches Used by Extant Studies.....	76
2.4.2	Theoretical underpinning	90
2.4.3	SLR 2 Discussion and Recommendation	91
2.5	SYSTEMATIC LITERATURE REVIEW 3: <i>A STATE-OF-THE-ART REVIEW FOR OSC INFLUENCING FACTORS-USING RIBA POW</i>	93
2.5.1	Review Protocol.....	99
2.5.2	Data sorting, cleaning and review outcomes	101
2.5.3	SLR 3 Analysis and Findings.....	114
2.5.4	Discussion.....	116
	CHAPTER SUMMARY	119
	CHAPTER THREE.....	121
3.0	THEORIES.....	121
	CHAPTER OVERVIEW	121
3.1	THEORIES AND ADOPTION	121
3.2	ADOPTION THEORIES IN OSC-RELATED STUDIES	123
3.3	ADOPTION THEORIES	126
3.3.1	Innovation Diffusion Theory (IDT)	126
3.3.2	Technology Adoption Models (TAM)	127
3.3.3	The United Theory of Acceptance of Use of Technology (UTAUT).....	128
3.3.4	The Concerns-Based Adoption Model (C-BAM).....	129
3.3.5	Awareness, Desire, Knowledge, Ability and Reinforcement (ADKAR) Model	133
3.4	COMBINING C-BAM AND ADKAR.....	136
	SUMMARY.....	138
	CHAPTER FOUR.....	140
4.0	METHODOLOGY.....	140
	CHAPTER OVERVIEW	140
4.1	RESEARCH METHODOLOGY (THEORETICAL PERSPECTIVE)	140
4.1.1	Research Philosophy	141
4.1.2	Research Ontology	143
4.1.3	Research Axiology.....	145
4.1.4	Definition of other mixed-method terms used in Research Philosophy	146
4.2	RESEARCH APPROACH.....	148
4.2.1	Definition of other mixed-method terms used in Research Approach.....	150
4.3	RESEARCH CHOICE (THE MIXED METHOD APPROACH)	151
4.4	RESEARCH METHOD (STRATEGY)	153
4.4.1	Data Synthesis	156

4.4.2	<i>Qualitative Approach</i>	158
4.4.3	<i>Qualitative Sampling</i>	162
4.4.4	<i>Interviewing</i>	166
4.4.5	<i>Interview Data Analysis</i>	168
4.4.6	<i>Interview Validation</i>	168
4.4.7	<i>Quantitative Approach</i>	171
CHAPTER SUMMARY		187
CHAPTER FIVE		188
5.0 ESTABLISHING UK-SPECIFIC OSC INFLUENCING FACTOS THROUGH QUALITATIVE APPROACH		188
<i>CHAPTER OVERVIEW</i>		188
5.1	CHAPTER INTRODUCTION	188
5.2	INTERVIEW SAMPLE FRAME	189
5.3	INTERVIEWEES' PROFILE	189
5.4	INTERVIEW DATA SYNTHESIS	195
5.5	INTERVIEW DATA ANALYSIS	195
	<i>Data Familiarisation</i>	202
5.5.1	<i>Content Analysis</i>	197
5.6.1	<i>Notion of Clusters</i>	201
5.5.3	<i>Thematic Analysis</i>	202
	<i>Theming Phase (Generating Initial Themes)</i>	202
	<i>Creating and Reviewing the Themes</i>	204
	<i>Define Themes</i>	204
5.6.4	<i>Inferences from The Findings and Discussions:</i>	220
CHAPTER SUMMARY		221
CHAPTER SIX.....		223
6.0 QUANTITATIVE APPROACH (QUESTIONNAIRE ANALYSIS).....		223
<i>CHAPTER OVERVIEW</i>		223
<i>PREAMBLE</i>		223
6.1	DESCRIPTIVE ANALYSIS (OVERVIEW OF SURVEY QUESTIONNAIRE)	226
6.1.1	<i>Data Demography</i>	226
6.2	EXPLORATORY ANALYSIS	237
6.2.1	<i>Data Pre-processing for exploratory analysis</i>	237
6.2.2	<i>Internal Reliability</i>	244
6.3	HYPOTHESIS	247
6.3.1	<i>Hypothesis Development</i>	247
6.3.2	<i>Formulating the Hypotheses ($H_{0,1-7}$)</i>	250
6.3.3	<i>Hypothesis Validation</i>	256
CHAPTER 7: ESTABLISHING THE MOST CRITICAL FACTORS THROUGH FEATURE SELECTION APPROACH		259
<i>CHAPTER OVERVIEW</i>		259
7.1	CORRELATION ANALYSIS	259
7.2	FEATURE SELECTION	270
7.2.1	<i>Feature Selection Models Used in this study.</i>	271
7.2.2	<i>Extracting the Critical Factors.</i>	275
CHAPTER 8: THE MACHINE LEARNING TO DEVELOPING OSC ADOPTION PREDICTION MODEL.....		281

CHAPTER OVERVIEW	281
8.1 DATA PREPARATION FOR ML DEVELOPMENT.	281
8.2 FEATURE ENGINEERING.....	284
8.2.1 Addressing Class Imbalance Using Synthetic Minority Over Sampling Technique (SMOTE) for ML application.	285
8.3 MACHINE LEARNING APPROACH.....	287
8.4 MACHINE LEARNING MODEL DEVELOPMENT	290
8.4.1 Data Splitting.....	290
8.4.2 List of Algorithms used for Model Development.....	294
8.4.3 Model Evaluation Measures.....	297
8.4.4 Developing the Models.....	302
CHAPTER 9.....	304
9.0 RESEARCH FINDINGS AND DISCUSSION.....	304
CHAPTER OVERVIEW	304
9.1 RESEARCH FINDINGS	304
9.1.1 Systematic Literature Review (SLR) Outcomes.....	304
9.1.2 Qualitative approach Outcomes.....	306
9.1.3 Quantitative approach Outcomes.....	307
9.1.4 Machine Learning Model Results.....	312
9.1.5 Selecting the Best Models.....	326
9.2 DISCUSSION.....	332
9.2.1 Critical OSC Influencing Factors to UKCI.....	335
9.2.2 Machine Learning Outcome.....	346
10.0 CONCLUSION.....	348
CHAPTER OVERVIEW	348
OBJECTIVE 1:	348
OBJECTIVE 2:	349
OBJECTIVES 3 AND 4:	349
OBJECTIVE 5:	350
THEORIES POSTULATED	ERROR! BOOKMARK NOT DEFINED.
10.1 STUDY IMPLICATIONS	ERROR! BOOKMARK NOT DEFINED.
10.1.1 Theoretical Implications	Error! Bookmark not defined.
10.1.2 Practical Implications.....	Error! Bookmark not defined.
10.1.3 Policy Implications.....	Error! Bookmark not defined.
10.1.4 Summary of Study Implications.....	Error! Bookmark not defined.
10.2 LIMITATIONS.....	355
10.3 FURTHER STUDIES/FUTURE WORKS	360
REFERENCES	362
PHD PLAN.....	445
APPENDICES.....	447
APPENDIX 1: DRIVERS IDENTIFIED FROM LITERATURE REVIEW (SLR 1).....	447
APPENDIX 2: BARRIERS IDENTIFIED FROM LITERATURE REVIEW (SLR 1)	463
APPENDIX 3: DETAILED DISCUSSION (DRIVERS AND BARRIERS)	494
APPENDIX 4: INTERVIEW CALL.....	516
APPENDIX 5: FACTORS IDENTIFIED FROM INTERVIEW ANALYSIS.....	520
APPENDIX 6: DETAILED DISCUSSION ON REVIEW FACTORS.....	525
APPENDIX 7: DETAILED CONTENT ANALYSIS DISCUSSION	547
APPENDIX 8: DETAILED THEMATIC ANALYSIS DISCUSSION.....	554

APPENDIX 9: SURVEY QUESTIONNAIRE	609
APPENDIX 10: DETAILS OF DROPPED FEATURES MAPPED TO KEPT FEATURE	622
APPENDIX 11: TOP 25 FEATURES SELECTED FROM EACH FEATURE SELECTION METHOD APPROACH	623

CHAPTER ONE

1.0 INTRODUCTION

Chapter Overview

Chapter One establishes the foundation of the thesis by contextualising the challenges and opportunities surrounding Offsite Construction (OSC) adoption in the UK. It sets out the research problem and aims, articulates the guiding objectives and research questions, and presents a strong justification for the study based on identified gaps in both industry practice and academic literature. The chapter defines the scope, assumptions, and limitations of the study, while explaining its dual philosophical positioning in pragmatism and critical realism. It introduces ADKAR and CBAM as theoretical models for understanding adoption behaviour and outlines the study's methodological flow, which combines three systematic literature reviews, qualitative interviews, survey development and analysis, critical factor identification using feature selection and predictive modelling using common machine learning algorithms. This structure sets the stage for a rigorous, insight-driven exploration of OSC adoption in the UK construction sector.

1.1 Background to the Study

The global construction industry is at a critical juncture, facing escalating challenges such as productivity stagnation, cost overruns, safety hazards, and environmental degradation and sustainability (*reduction in carbon release and responsible management of natural resources to ensure balanced ecosystem*) among others owing to the traditional construction approaches employed (Broadhead et al., 2023; Egan, 1998; Jayawardana et al., 2023; McKinsey Company et al., 2019; Opoku et al., 2019) amidst other factors. In response to these persistent traditional

construction approach shortcomings, Offsite Construction (OSC), one of the approaches to Modern Methods of Construction -described as the dominant approach, has emerged as a transformative solution that relocates substantial portions of building construction activities from traditional site-based settings to controlled, factory environments (Gao et al., 2019; Zhai et al., 2014). OSC has shown to offer improved quality, shortened project timelines, safer working conditions, enhanced cost predictability, and greater sustainability (Goodier & Gibb, 2007; KPMG, 2016; Pan & Sidwell, 2011), aligning with Sustainable Development Goals (SDGs) 9, 11 and 13 in pursuit of a net-zero carbon target– a major environmental sustainability target.

In the United Kingdom, the strategic relevance of OSC is well documented in policy instruments such as Construction 2025 agenda, the Transforming Infrastructure Performance (TIP) Roadmap, the Construction Playbook, and such, all of which advocate for increased adoption of Modern Methods of Construction (MMC) to boost industry productivity and innovation (CLC, 2020; GOV.UK, 2016; Han et al., 2022; HM Government, 2013; House of Commons, 2019). Despite these high-level commitments, OSC adoption in the UK remains disappointingly limited—a pattern attributed not only to technical and economic constraints but also to more nuanced challenges like social ones, e.g., resistance to change (Looby et al., 2022; Wusu, Alaka, Oseghale, Balogun, et al., 2025), behavioural inertia (Saad, et al., 2023c; Wusu, Alaka, Oseghale, Balogun, et al., 2025); and others like fragmented supply chains (Arif et al., 2017a; Olayiwola et al., 2025), and limited organisational readiness (Blismas et al., 2006; Nadim & Goulding, 2010).

Today, OSC concept is gradually gaining traction within the Architecture, Engineering, Construction, and Operations (AECO) sectors but not with a corresponding adoption rate. Achieving widespread adoption requires a clearer understanding of the factors influencing

uptake and usage. This research is thus motivated to identify, evaluate and model the critical wider OSC adoption influencing factors—especially through the application of Machine Learning (ML).

1.2 Offsite Construction and Artificial Intelligence Concepts

1.2.1 *The Offsite Construction Concept*

The concept of OSC is not entirely new. Historical accounts trace its origins back to the 17th century, when Dutch settlers transported and assembled timber-framed structures along the Connecticut River (Thomas, 2006). Its application resurfaced prominently after World War II, when prefabricated housing was employed in response to the urgent demand for mass accommodation for returning soldiers. Over time, the terminology surrounding OSC has evolved, including nomenclatures such as Precast Construction, Modular Construction (MC), Industrial Building Systems (IBS), Design for Manufacture and Assembly (DfMA), and Modular Integrated Construction (MiC) (Lou et al., 2022; Olawumi et al., 2022). In this study, the term Offsite Construction (OSC) is adopted as an umbrella term for all non-site manufacturing and preassembly approaches aimed at achieving efficient, scalable building solutions.

Offsite Construction (OSC) is a prefabrication-based construction method situated within the broader category of Modern Methods of Construction (MMC) (NHBC, 2016). It involves the manufacturing of building components in a controlled factory environment, followed by transportation and on-site assembly using coupling or hinging systems (Yan et al., 2018a). The concept is recognised as a disruptive and innovative approach capable of addressing many limitations associated with traditional construction methods (Blismas & Wakefield, 2009)

Some of the well-established categories of Offsite construction are Pre-manufactured 3D Primary Structural Systems, Pre-Manufactured 2D primary Structural Systems (Panels), Pre-manufactured Components (Non-systemised Primary Structure), Pre-manufactured Non Structural Assemblies and Sub-Assemblies, and Traditional Product-led Site Labour Reduction. (Goodier & Gibb, 2007; RIBA, 2021). *Refer to Section 2.2.1 for details.*

1.2.2 OSC Definitions

There are various definitions of OSC by authors, with emphasises on the focus and characteristics of their studies. For example, Boothroyd, (1996) defined OSC as a systematised effort to reduce part counts and optimise manufacturing potential. (Goodier & Gibb, 2007) describe it as the manufacture and preassembly of components off site prior to their installation. BuildOffsite, through the UK Construction Industry Council (CIC, 2013), defines OSC as any process where the proportion of construction activity completed offsite exceeds 60% of the total value added. Similarly, Smith & Quale, (2017) described OSC as the design, planning, and fabrication of building elements away from their final location to accelerate the delivery of permanent structures.

From these definitions, two common themes emerge- OSC enables almost uninterrupted productivity cycle irrespective of weather conditions, and it relies on a logistics-driven sequence of production and assembly. However, majority of the definitions fall short of encompassing OSC's full spectrum—from non-volumetric component manufacturing to full volumetric modular systems (RIBA, 2021). For this study, OSC is defined as a prefabrication and assembly methodology that enables rapid construction by mass-producing building elements in a factory setting, transporting them to the project site (point of use) through a series of logistics system, and technically assembling them through engineered connections (hinging and coupling systems) for use.

1.2.3 *Artificial Intelligence (AI) and Machine Learning (ML) Concepts.*

Artificial Intelligence (AI) is a branch of computer science that develops systems capable of performing complex tasks (Gupta et al., 2022; Yevu et al., 2025). AI enables machines to understand language, interpret visual data, and act autonomously in various environments. They can be designed to perform specific tasks or general tasks across domains. Instead of explicit programming for every scenario, these systems learn from massive data sets to identify patterns, make predictions, and adapt to new inputs. Common uses include self-driving cars, diagnostic tools in healthcare, content creation (generative AI), and recommendation systems (Jordan & Mitchell, 2015; McCarthy, 2007).

Machine Learning (ML) is an arm of Artificial Intelligence (AI) focused on analyzing data from the sample data set provided, developing models from trained data sets and predicting outcomes from the testing data set (Wusu et al., 2022). It employs algorithms and statistical models to learn from the training data set. Machine Learning can be used in supervised training, unsupervised training and reinforcement training data sets (Egwim et al., 2021) One of the major objectives of ML is the use of trained data set to identify a typical pattern or trend in the data set and test such patterns to predict a probable outcome. Some features that put Machine Learning ahead of other analytical tools are its ability to identify patterns or rhythms earlier unknown in data, the variables options for associating two or more factors and categorization of factors by similarities. Moreover, it can also be used to predict outcomes based on specific criteria, group objects or activities based on their history *(See Section 2.4.4. for Machine Learning application to construction industry)*

Machine learning can be a classification or regression task based on the type of dataset used for development. In deciding the critical features, a single feature selection approach (model) could be used, but a in more rigorous or complex task like this study, a group of models is advisable and preferred in establishing the features most critical to the dependent variable—

that is the variable being analysed for (*See Preamble in Chapter 6*). In selecting models used for prediction, **generalisability and interpretability** are two critical considerations looked at, especially in studies for non-computing experts or sectors (*See Section 8.3, Page 290*). In selecting the best performing models, a combination of evaluating measures are considered (*See Section 8.4.3*) and usually, and also for this study, Area Under Curve (AUC) and Accuracy were the most preferred. (*See last paragraph in Section 8.4.3*).

For this study, 10 feature selection models were considered for establishing the most critical factors influencing OSC adoption in the UK and 10 model development algorithms were evaluated before selecting the best predictive one. Prediction was necessary because for the likelihood of attaining the proposed 25% usage and because stakeholders are sceptical about the viability and continuity of OSC (Ridings, 2024).

1.3 Offsite Construction in the UK

Globally, many nations have embraced OSC to modernise and improve construction delivery. In Europe, Denmark has increased its OSC uptake by 40%, followed by Austria with 33% while Germany, the Netherlands, and Sweden reported 15% growth (Jiang et al., 2020). In Asia, China aimed for 60% urbanisation by 2020 through OSC-led strategies (Jiang et al., 2020); Japan delivers approximately 150,000 homes annually using OSC (Oti-Sarpong et al., 2022a; Zhai et al., 2014), and Singapore houses over 80% of its urban population in OSC-based developments (Shang et al., 2020). Malaysia use of OSC in public-sector was reported at 84% (Azalea, 2023). In America, the United States and Canada report about 5% OSC usage across various building types (Broadhead et al., 2023), while Australia's uptake is estimated at around 3% (Hosseini et al., 2018a). By contrast, Africa is yet to come into OSC mainstream (Kolo et al., 2014; Rahimian et al., 2017). But the UK, despite its historical association with prefabrication, particularly after WWII, has not maintained its early momentum in embracing

OSC, recording averagely 5-10% adoption (ConstructionNews, 2024; House of Lords, 2022; Savills, 2024), a record below its European counterparts.

Though Offsite Construction (OSC) is strategically significant in addressing inefficiencies within the UK construction sector, its adoption continues to lag behind expectations. This state persists in the face of mounting evidence that OSC can enhance productivity, reduce waste, improve worker safety, and contribute to net-zero carbon goals (Goodier & Gibb, 2007; KPMG, 2016; McKinsey Company et al., 2019). Policy frameworks such as Construction 2025 and the Construction Playbook advocate for the integration of modern construction approaches like OSC into mainstream construction, yet widespread uptake remains sporadic, fragmented and below target (HM Government, 2013; IPA, 2021).

1.4 Problem Statement

Studies show that a large proportion of construction projects in the UK still rely heavily on traditional, labour-intensive methods (Blismas & Wakefield, 2009; Farmer, 2016). Meanwhile, the UK continues to struggle with chronic housing shortages, consistently falling short of its housing delivery targets. While the UK needs to deliver up to 340,000 homes per year, production has hovered around 150,000 annually (LetsBuild, 2023; Savills, 2024). This disparity underscores a deepening need for an innovative and scalable solutions such as OSC and further reinforces the need for this study at this time.

Despite early engagement with Offsite Construction (OSC) during the post-war prefab era, the UK currently lags behind several European and Asian countries in terms of OSC adoption. Although OSC aligns with many of the UK government's construction goals—particularly net-zero carbon emissions, supply chain integration, and accelerated housing provision (ConstructionNews, 2024)—it is yet to achieve meaningful penetration across the sector

(House of Lords, 2022). Efforts by the UK government to promote OSC through collaborations with bodies like the Construction Industry Council (CIC), BuildOffsite, and the Infrastructure and Projects Authority (IPA) have not yielded widespread adoption (UK Parliament, 2018). Industry stakeholders have continued to show a sluggish response in achieving widespread adoption, raising concerns among policymakers and stakeholders (UK Parliament, 2019; Ridings, 2024). Knowledge gaps around installation techniques, component supply limitations, logistical complexity, and such., have also hindered uptake, particularly in small to medium-sized enterprises (lowe & Oxland, 2020; UK Parliament, 2018; Zhang et al., 2024), keeping OSC adoption slow and low.

The housing shortage in the UK remains severe, with the supply consistently falling short of the projected demand (Hazlegreaves, 2022). For instance, over 230,000–250,000 housing units needed to be delivered annually between 2015-2020 to bridge the shortfall, actual outputs remain far below target (NHF, 2018; Barton & Wilson, 2023). Recent reports, building on earlier data, noted that 300,000-350,000 house are required for the next ten (10) years to break even on housing shortage backlog (Baron, 1983; Charlson & Dimka, 2021; Savills, 2024; UK Parliament, 2019).

Despite traditional construction methods, which are heavily reliant on on-site manual labour, being criticised for their low productivity, prolonged timelines, and high carbon emissions (Perry et al., 2021; Wang & Sinha, 2021a), it still dominates the UK construction context (Saad, et al., 2023c). These inefficiencies clash directly with the UK's net-zero carbon ambitions and its goals for rapid sustainable urban growth.

In the light of these challenges and opportunities, this study provides a more nuanced understanding of OSC adoption by examining the interplay of constructs that leads to adoption

factors. It seeks to go beyond descriptive literature accounts to developing OSC project-data-informed, predictive model of adoption likelihood—drawing on mixed methods inquiry and theory-informed frameworks to uncover the most critical factors influencing OSC adoption within the UK construction industry.

1.5 Literature Synthesis

The UK government expects 25% OSC/MMC adoption for all UK construction projects, especially government funded projects (CIC, 2013; CLC, 2020). There is however no government-wide, hard **deadline** by which all UK construction projects must use 25% OSC. The adoption is encouraged through policy and frameworks rather than a mandate with a **specific end date** for that exact percentage (GOV.UK, 2021). Though, the government expects that by the end of 2025, at least, most of the new homes will be built using Modern Methods of Construction (MMC), which includes OSC/modular construction (Jeusu & Burns, 2025). This is a sector-specific expectation, not a ‘hard’ target for the entire industry.

Various studies have examined OSC influencing factors as drivers and barriers (Arif et al., 2017a; Blismas & Wakefield, 2009; Gan, et al., 2018), but the analytical and theoretical foundations lack a direction that can lead to the desired 25% usage aimed at by UK government. Most of these studies either generalise OSC influencing factors without exploring their granular subcomponents or focus exclusively on technical elements without considering behavioural and institutional transitions (Pan & Sidwell, 2011; Zhai et al., 2014). Moreso, there is a lack of robust transition frameworks that incorporate change management and predictive tools to model the likely uptake of OSC in various contexts (Wusu et al., 2025; Zhang et al., 2024)

A growing body of research attributes low OSC uptake to a complex interplay of behavioural, organisational, informational, technical and systemic barriers (Blismas et al., 2006; Nadim &

Goulding, 2010; Pan & Sidwell, 2011). These include limited awareness (Wusu, Alaka, Oseghale, Yusuf, Sunmonu, & Akinyemi, 2025), resistance to change (Wusu, Alaka, Oseghale, Balogun, et al., 2025), lack of technical expertise (Wuni & Shen, 2020b; Wusu, Alaka, Oseghale, Yusuf, Sunmonu, Ajayi, et al., 2025), fragmented supply chains Zhai et al., (2019), and the absence of robust data management systems to support decision-making (Wuni & Shen, 2022). However, these factors are frequently explored in isolation, often through either qualitative or quantitative lenses, limiting our understanding of how they interact or predict adoption in practice.

Furthermore, there is a notable lack of empirical studies that integrate qualitative insights with data-driven predictive modelling to understand how multiple variables combine to affect OSC adoption outcomes. In particular, research rarely applies or tests theoretical models of change management such as ADKAR or CBAM to examine individual and organisational readiness for adopting new construction methods.

Without such integrated, theory-informed, and empirically grounded research, attempts to promote OSC adoption may continue to fall short of expectations. Thus, there is a pressing need for a comprehensive, mixed or multi-methods investigation that not only identifies key influencing factors but also develops a predictive framework capable of informing theory, policy, practice, and strategic planning within the construction sector.

Moreover, the recent written evidences appraised by the UK Parliament (UK Parliament, 2023, 2024b) and the call for funds withdrawal from OSC related researches (Brown, 2024; Ridings, 2024) further elevated the desire to look deeper into the critical OSC influencing factors, strengthen the adoption of rigorous measures to unearth these factors and develop an adoption

prediction model for OSC adoption likelihood in the UK- a template that can be considered by any nation with OSC adoption challenge.

1.6 Knowledge Gap

Drawing from the insights in the literature review, a few gaps were observed from extant works on OSC adoption. Some studies have explored some of the granular elements of adoption factors but failed to relate how such granular elements constitute the generalised drivers or barriers. *Granular factors are micro elements or building blocks that make up a bigger factor, e.g., initial cost, funding, mortgaging, and other finance/credit issues making cost factor; managing cranes, buffer/hedging area, site constrain, wrong delivery making up supply chain management; professional awareness, recreating awareness, varying awareness level, making up awareness factor among others.* For instance, in an assemblage knowledge study as a limiting factor for OSC adoption, Chao et al., (2007) addressed the use of Radio Frequency Identifying Device (RFID) in component installation and traceability like a stand-alone factor, not noting it as an element of supply chain management or a logistics barrier.

Additionally, in some areas, reported influencing factors are still found to have both inhibitory and driving impacts on wider OSC adoption, e.g., cost, supply chain management and logistics, as observed in Pan & Sidwell, (2011) and Zhai et al., (2018a), but distinctions were not made as to when they act as driver or barriers and what granular factors makes them so in each case. This limitation could be due to studies on OSC being more of reviews and quantitative appraisals, lacking rich depths on understanding OSC adoption. Following this lopsided understanding from the reports on OSC factors, potential adopters are left in a debate of what OSC has to offer beyond traditional construction method, thus, contributing further to low OSC adoption. This confusion is further exacerbated by the absence of an OSC project data

repository in the UK to effectively appraise what boundary such influencing factors or elements belong to and how much OSC has to offer them if adopted (Ridings, 2024; Wusu et al., 2022).

Further, this study noted that more attention has been given to the production and construction phase of OSC with little or no attention given to those who want to occupy the building (Wusu, Alaka, Oseghale, & Oriowo, 2025), (*See SLR 3*), though some attention seems to be paid to house builders and housing associations providing the buildings (Pan et al., 2007a, 2008).

Moreso, most studies have either relied on content analysis (count of reported factors from literatures and qualitative studies), followed by their themes or simple statistical analysis, falling short of capturing the complex, interacting factors influencing OSC adoption in practice or providing the rich qualitative context from textual analysis (Wusu, Alaka, Oseghale, Yusuf, Sunmonu, Ajayi, et al., 2025; Zhang et al., 2024), thus presenting shallow explanation that more or less satisfy basic hypothetical observations. No reported study has combined qualitative insights with advanced predictive analytics to unravel OSC adoption and make solid project data-driven recommendations. While partial efforts such as those by Yevu et al., (2025) and Olawumi et al., (2022) employed techniques like PLS-SEM in construction analytics, very few, if any, have translated qualitative findings into OSC project-informed machine learning-based predictive frameworks for OSC adoption. While, studies like Dixon-Ogbechi & Adebayo, 2020; Gan et al., 2018 and Wuni & Shen, 2019 have attempted analysis like Structural Equation Modelling, Fuzzy technique and Analytical Hierarchy Process to address OSC adoption possibilities, these models are primarily explanatory and confirmatory than predictive. Addressing this gap is particularly significant given calls for proactive, data-driven policy-making on the future of OSC in the UK (Zhang et al., 2024; UK Parliament, 2019) as well as helping prospective client make data-drive decision on using OSC for projects. This ML approach used most commonly reported generalisable and easy to interpret machine

learning algorithms e.g., Logistic Regression, Support Vector Classifier, Random Forest, KNeighbour, and others (Ahn et al., 2017; Datta et al., 2024), rather than experimenting with highly complex or less interpretable models such as deep neural networks.

Similarly, exploring the adoption of a form of building method implies changing from an ‘old or existing’ methodology to the newly presented one. Sadly, not many studies have evaluated the transition from traditional methods to offsite methods in the light of change management (Wusu, Alaka, Oseghale, Yusuf, Sunmonu, & Akinyemi, 2025). This has left loopholes in the efforts concerted at successfully transitioning to OSC. The absence of change management approach seems to have made a lot of efforts go into the technical part of OSC adoption with little attention to some social, non-technical aspects. Whereas, transitioning requires a holistic appraisal (Y. Zhang et al., 2024). For example, a studies by Wusu, Alaka, Oseghale, Balogun, et al., (2025) and Wusu, Alaka, Oseghale, Yusuf, et al., (2025), using change management tools like gap analysis and ADKAR and CBAM showed that there is a wide gap between awareness and perception of general end-users and construction industry professionals regarding understanding the workings of OSC.

To address these gaps, this study followed the recommendation of Goulding et al., (2014) that several construction areas and causal issues should be considered (*Refer to Section 2.3*). It critically analysed OSC adoption in the UK through an exploratory sequential mixed methods approach, and industry and theoretical guides. It built on studies like (Wuni, 2022; Wuni & Shen, 2019) which have attempted to breakdown OSC influencing factors, though not stating such breakdowns as constituting elements determining the influence of such factors on adoption. However, the Pareto analysis employed gave insight into which of the breakdowns have vital or trivia influence on such adoption categorisations. Further, this study triangulated findings from systematic literature reviews and industry interviews, to develop a quantitative

survey. The use of advanced feature selection and machine learning modelling allows for both explanatory and predictive insights. In doing so, this research responds directly to both academic and industry demands for evidence-based, scalable solutions to widen OSC adoption.

Additionally, the current study is grounded in ADKAR (Awareness, Desire, Knowledge, Ability, Reinforcement) and the Concerns-Based Adoption Model (CBAM), offering structured perspectives for analysing both individual and organisational change in the context of OSC. These frameworks guided the interpretation of behavioural and systemic resistance and readiness; an approach rarely explored in combination with predictive modelling techniques. Finally, by combining content and thematic analyses findings for SLRs and qualitative interviews with machine learning algorithms, this study generates both descriptive, predictive and prescriptive insights—bridging a critical methodological gap and contributing to a more actionable understanding of OSC adoption within the UK’s evolving construction landscape.

1.7 Justification for the Study

The increasing urgency to modernise the UK construction industry, coupled with growing calls for sustainable, efficient, and cost-effective building solutions, places Offsite Construction (OSC) at the forefront of innovation agendas (Agapiou, 2022; Miles, 2021; Pan & Sidwell, 2011; RIBA, 2020; Saad, et al., 2023a). OSC has been promoted as a strategic response to issues such as productivity lag (Goh & Goh, 2019a; Nath et al., 2015), skilled labour shortages (CITB, 2019; Ginigaddara et al., 2021a), and rising housing demands (Arif et al., 2017a; Perry et al., 2021). Despite these potential, OSC adoption in the UK remains fragmented, under-implemented, and poorly understood, especially when compared with countries like Sweden, Germany, Japan or Singapore, where adoption is government-driven and more coordinated (Oti-Sarpong et al., 2022a; Steinhardt & Manley, 2016).

To date, no known studies have triangulated findings from a context-focused systematic review with interview data to inform the design of a context-based structured survey instrument and then employed feature selection and supervised machine learning to develop adoption prediction models for OSC. This is despite evidence that machine learning models have proven successful in other construction applications such as predicting construction safety hazards (Tixier et al., 2016), CI bankruptcy (Alaka, et al., 2018; Alaka et al., 2019), and construction equipment activity recognition classification (Akhavian & Behzadan, 2015a).

By identifying and validating data-driven, context-relevant predictors of OSC adoption, this research fills a critical gap in both academic discourse and construction practice. It contributes evidence-based insights for enhancing OSC uptake- insights that are urgently needed given the UK's underwhelming performance despite ambitious housing provision (Barton & Wilson, 2023; CIC, 2013; Lymer, 2022; Pan et al., 2008), net-zero carbon targets (Karlsson et al., 2021; Laovisutthichai & Lu, 2021; Lymer, 2022; Osmani & O'Reilly, 2009) and recent call to scrap OSC idea, describing invest in it as a waste of tax-payers' money (Brown, 2024; Ridings, 2024; UK Parliament, 2023).

1.8 Research Aim and Objectives

Study Aim

The study aims at establishing the critical OSC adoption influencing factors in the UK using a machine learning (ML) approach. This is being done with a view to predict wider OSC adoption likelihood for proposed construction projects.

Research Objectives

1. To conduct systematic literature review (SLR) in identifying and synthesising commonly reported OSC adoption influencing factors across international contexts, including granular (un)popular ones.
2. To evaluate and establish, from the globally identified OSC adoption influencing factors, the relevant and applicable ones to the UK context through qualitative interviews with UKCI professionals.
3. To triangulate findings from the interview analysis with a UK-focused SLR in designing a UK context-specific survey instrument for quantitative data collection.
4. To identify and establish the most critical factors influencing OSC adoption in the UK through quantitative analysis and feature selection (FS) techniques using ten (10) commonly identified FS algorithms/models.
5. To develop a ML predictive model with the identified critical factors using ten (10) commonly identified ML algorithms and determine the best-performing predictive model for OSC adoption in the UK.

1.9 Research Questions

Aligned with the research aim and objectives, the following questions guided this study:

1. What critical factors influencing Offsite Construction (OSC) adoption have been identified across global and UK-specific context?
2. How can quantitative project data be generated for establishing the most critical factors influencing OSC adoption in the UK?

3. Which machine learning model(s) offers the best OSC adoption prediction performance likelihood for the future of OSC in the UK?

1.10 Research Methodology

Philosophical Positioning

The philosophical foundation of this study is underpinned by pragmatism, reinforced by critical realism, aligning with the study's mixed methods strategy and focused on both exploration and prediction in Offsite Construction (OSC) adoption. Philosophical positioning in research reflects how reality (ontology), knowledge (epistemology), and values (axiology) are perceived, which in turn influences the methodology and method choice (Creswell & Creswell, 2018; Husband, 2020).

This study's core aim, to identify, establish, evaluate, and predict the critical factors influencing OSC adoption in the UK, required an approach that accommodates and blends both qualitative contextual understanding and quantitative generalisability of OSC adoption factors. Pragmatism philosophical stance offers the required methodological flexibility by prioritising the research problem over allegiance to a single philosophical tradition (Creswell, 2003; Morgan, 2014). By this, the study neither lend itself to the positivism nor interpretivism paradigms but employed the best means to address the research problem and achieve the research aim. It employed systematic literature reviews for knowledge synthesis, interviews for meaning-making (extraction) and knowledge consolidation, quantitative approach for factor-criticality evaluation and machine learning for data-driven prediction, allowing the researcher to combine the strengths of both interpretivism and positivism (Choy, 2014; Fellows & Liu, 2015) .

While pragmatism enabled the integration of multiple methods, the deeper ontological lens of critical realism was employed to frame the complexity of OSC adoption. Critical realism assumes that reality exists independently of human perception, but access to it is mediated through social, structural, and cognitive filters (Bhaskar, 2008; Pole, 2007). In construction innovation contexts such as OSC adoption, this position is particularly useful because it allows the study to account for underlying generative mechanisms (Agyekum-Mensah et al., 2020; Almalki, 2016; Tashakkori & Teddlie, 1998; Tsz Wai et al., 2021), such as institutional culture, technological systems, or user perceptions, that may not be directly observable but influence outcomes (Sutrisna, et al., 2018).

This dual approach is critical for understanding OSC as both a technical innovation and a socio-cultural practice. While the interpretation of qualitative interview data and synthesis of perceptions align with interpretivist constructs of meaning-making, typical of critical realism, quantitative analysis and prediction through machine learning are grounded in observable correlations (consistent with positivist tendencies within pragmatism) (Afolayan & Oniyinde, 2019; Almalki, 2016; Feters et al., 2013; Proudfoot, 2023). Together, they create a complementary worldview that accepts the partiality of knowledge, while striving for practical, explanatory, and actionable insights (Maxwell & Loomis, 2003).

Theoretical Positioning

The study's theoretical foundation draws from two change management models and one industry framework: the Concerns-Based Adoption Model (CBAM), ADKAR model and the Royal Institute of British Architects Plan of Works (RIBA-PoW). The CBAM framework focuses on the stages of concern and levels of use individuals exhibit during innovation adoption (Hord, Roussin, et al., 2013). It highlights how users' perceptions evolve over time and provided a conceptual lens for interpreting interviews and validation feedback. The

ADKAR (Awareness, Desire, Knowledge, Ability, and Reinforcement) model, on the other hand, emphasises internal and external influencing factors in a system or organization in response to change (Hiatt, 2006), offering a suitable framework for analysing human/organisation-centric OSC adoption factors. It was employed to conceptualise how construction professionals and end-users become aware of, learn about, and internalise OSC building characteristics. The RIBA-PoW provides an industry guide to understanding construction stages of work as outlined for UK construction practices. It was used in line with the MMC overlay of works to appraise the work order of OSC against industry practise in understanding OSC adoption state-of-the-art. The trio models align with the critical realist orientation by acknowledging social reality as stratified and emergent, and with pragmatism by offering applied tools for real-world inquiry and intervention (Fullan, 2001; Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025).

In summary, this study's philosophical stance and theoretical grounding were carefully selected to suit the multi-layered, interdisciplinary, and applied nature of OSC adoption research. The integration of pragmatism and critical realism, supported by ADKAR, CBAM, RIBA-PoW ensures that the findings are not only analytically robust but also exploratory, explanatory, transferable, generalisable and actionable for construction professionals, researchers, and policymakers (Kawulich, 2009; Momani et al., 2017; Wacker, 1998)

Research Method

Building on this philosophical and theoretical foundation, the research followed a structured, multi-phase mixed methods design. The first phase involved a global systematic literature review (SLR) to identify widely reported OSC adoption factors (Jin et al., 2018; O'Neill & Organ, 2016). Finding from this review informed the interview protocol questions used to qualitatively explore OSC from UKCI professionals (Bloomberg & Volpe, 2015; Clarke &

Braun, 2013; Fetters et al., 2013). A second review was done to examine the research approaches (theoretical and analytical measures) used to address OSC adoption from the extracted articles (Ehwi et al., 2022). This was followed by a third review, a UK-specific SLR, which, combined with insights from semi-structured interviews with UK construction professionals, allowed for the triangulation of context-relevant factors (Boulder & Research, 2012; Brannen & Moss, 2012; Tashakkori & Johnson, 2021). These factors were then operationalised into a quantitative survey questionnaire, designed to capture the prevalent and perceived criticality in the questionnaire constructs (Adams & Cox, 2008; Döringer, 2021; Gregar, 2014; Onwuegbuzie et al., 2010; Tashakkori & Teddlie, 1998). In the final phase, the collected survey data was analysed with rigorous feature selection method, using multiple techniques, to extract critical OSC adoption predictors (Agapiou, 2022; Kotronoulas et al., 2023; Mikalef et al., 2019; Tixier et al., 2016). These features were subsequently used to train a suite of commonly identified and easily interpretable machine learning algorithms like Random Forest, XGBoost, Logistic Regression, and such. Model performances were assessed using AUC-ROC and accuracy as grand metrics. This full-cycle approach reflects a coherent alignment between philosophical stance, theoretical lens, methodological sequence, and analytical rigour (Agyekum-Mensah et al., 2020; Onwuegbuzie & Hitchcock, 2015; Patton, 2002; Plano-Clark et al., 2008).

1.11 The Mixed Method

Mixed method design is research approach that incorporates the integration of both the qualitative and quantitative research approaches, leveraging on the strength of each to complement the weakness of the other. Reports have it that the use of mixed method did not come into research stream until the mid-20th century (Creswell & Creswell, 2018), though it has long existed in many other various forms such as combined research, multimethod research,

consolidation research, and others. (Plano-Clark et al., 2008). Mixed method classification have been attempted by various authors but the four routes to mixing research according to Plano-Clark et al., (2008) were evaluated before deciding on the one for this study. The four routes are triangulation, explanatory, exploratory and embedded mixed methods. The most applicable of the four to this study is the exploratory design because it allows for the researcher to move from qualitative study to mixing the qualitative findings with theory or SLR in developing instrument(s) which shall be used to quantitatively test or measure the qualitative findings. Two things considered in the mixed method research design were timing and weighting. While the timing of the mixing was after qualitative analysis, the weighting was on quantitative analysis, highlighting probable criticality. While the interpretation emphasises the qualitative build-up, the quantitative results is used to test and generalize the findings. The measuring instrument developed in this study was a survey questionnaire.

1.12 Study Contribution

This study contributes significantly to OSC adoption pursuit and broader construction innovation discourse through multi-phase approach, addressing critical gaps in addressing and forecasting OSC adoption within the UKCI in the underlisted major ways:

- ***Empirical Contribution:*** The study captured a much granular, project data-driven identifications of the most critical factors influencing OSC adoption in the UK. Drawing from the three SLRs (global, theoretical-methodological, and UK-focused) and expert interviews with industry professionals, it captured both global and local dimensions of OSC dynamics. Unlike prior studies that often focused on isolated barriers and generic enablers, this thesis contextualises adoption factors within the lived realities of UK construction industry context. The integration of over one hundred (100) variables and the subsequent reduction to the most influential predictors using ten (10)

feature selection techniques enhances the empirical robustness and interpretability of OSC adoption predictors.

- ***Methodological Contribution:*** The study adopts a multi-layered and rich methodological structure, integrating literature synthesis, qualitative triangulation, and ML-based predictive modelling -a rare but powerful analytical combination in OSC adoption studies. By operationalising qualitative insights into a structured quantitative instrument and, applying ten feature selection and ten classification-based machine learning models, the study not only identifies but prioritises critical adoption factors. The modelling process employed rigorous cross-validation, performance testing (AUC-ROC, test-accuracy), and nine (9) random state iterations for generalisability, offering a replicable blueprint for future research in construction innovation and technology adoption in the UK and beyond.
- ***Theoretical Contribution:*** By applying the CBAM (from education) and ADKAR (from change management) frameworks with RIBA-PoW, the study advances theory by providing a structured interpretive lens to understand behavioural and organisational readiness that can redefine the approach to unearthing OSC adoption issues beyond what extant literatures present. Combining the theories in a single study is novel. While CBAM provides insight into stakeholder concerns and readiness across stages of adoption, ADKAR captures the micro-processes of behavioural and organisational transformation. This trio-theoretical grounding enables a deeper understanding of how individual, organisational and institutional factors interact to shape adoption decisions and policies and extend the wider adoption possibilities of OSC through increased awareness as seen in the extension of ADKAR to $ADKAR \Rightarrow A$.

- ***Practical Contribution:*** this thesis presents a predictive decision-support framework that can guide OSC implementation strategies. The best-performing ML models provides a scalable tool for forecasting OSC adoption likelihood across various project conditions and stakeholder environments. The study's findings illuminate infrastructural, behavioural, technical, and policy-levels levers that can be targeted to boost OSC uptake. For instance, factors such as logistics readiness, supply-chain integration and design flexibility perception were shown to critically influence adoption decisions. The study approach and finding offers the formulation of targeted adoption strategies for academics, industry stakeholders and policymakers and focal points for interventions, thus further aligning the construction industry with Sustainable Development Goals (SDGs) 9, 11 and 13 in pursuit of a net-zero carbon target.
- ***Contribution to Construction Data Science Application and Digitalization:*** by aligning construction innovation with data science, this study contributes to emerging agenda of digital transformation in construction. It demonstrates how AI-driven analytics can contribute to decoding complex adoption behaviours and enable evidence-based decision-making in policy and industry. This bridges the traditional gap between qualitative narratives and quantifiable outcomes, thus, positioning OSC within a more actionable, data-informed trajectory.

1.13 Scope and Delimitations

Scope of the Study

This study investigated the adoption of Offsite Construction (OSC) within the UK construction industry, with specific attention to the building and housing sectors, as these represent the domains where OSC is most actively promoted and implemented (Agapiou, 2022; Alonso-Zandari & Hashemi, 2017; Oliveira et al., 2017). The investigation is limited to OSC as a

construction methodology, excluding other modern methods of construction (MMC) not defined by significant offsite fabrication or assembly, e.g., 3D printing or digital twin technologies (KPMG, 2016; Blismas et al., 2006). It also limits its geographical scope to United Kingdom practices and stakeholders, despite drawing on global OSC literature for initial factor identification and aggregation.

The study used literature from 2000 to 2021 for global OSC influencing factor SLR and 2000 to 2024 for UK-focused SLR. This is justified by the shift in global attention toward sustainability, modularisation, and construction innovation that began gaining traction at the turn of the 21st century (Hwang et al., 2018; Wuni & Shen, 2022). Only English-language peer-reviewed literature and credible grey sources (like government reports, and reputable industry documents) were considered fit for additional industry knowledge.

Methodologically, the research employs a multi-phase mixed-method design. It begins with a global SLR to identify commonly reported OSC adoption factors. This is followed by a UK-focused SLR and semi-structured interviews with construction professionals to validate and contextualise these factors. The triangulation of qualitative findings and systematic peer-reviewed journal insights, consistent with approaches recommended by Plano-Clark et al., (2008) and Tashakkori & Teddlie, (1998) for sequential explanatory mixed methods were used to design a structured survey questionnaire. The survey data was analysed quantitatively. Finally, feature selection techniques and machine learning algorithms were applied to identify the critical UKCI OSC influencing factors and the identified factors were used to develop predictive models for OSC adoption, using evaluation metrics such as AUC-ROC and test accuracies to compare model performance in predicting critical UKCI OSC influencing factors.

Delimitations of the Study

This comprehensive research design establishes clear boundaries for feasibility and focus. First, it deliberately restricts literature selection to sources published post-2000 to capture only recent and relevant OSC trends in theory and practice (Drescher & Edwards, 2019; HM Government, 2013; O'Neill & Organ, 2016; Oti-Sarpong et al., 2022a). Second, it mainly concentrates on residential and commercial buildings, excluding infrastructure projects (e.g., roads, bridges) due to their different design, procurement, and regulatory landscapes (Andersson & Lessing, 2020a; Goulding & Rahimian, 2019a; Young et al., 2020).

The study further limits its exploration to most commonly reported easy to interpret machine learning algorithms e.g., Logistic Regression, Decision Tree, Random Forest, XGBoost, and others (Ahn et al., 2017; Datta et al., 2024; Sokolova, & Lapalme, 2009) rather than experimenting with highly complex or less interpretable models such as deep/artificial neural networks. This ensures that the models remain explainable to non-technical construction stakeholders and are practically usable in decision-making contexts. This decision aligns with research by Yevu et al., (2025), who cautions that more complex AI models, such as deep learning, may lack explainability for construction professionals.

Lastly, the scope of the study is limited to theoretical model development, not deployment. That is, while the predictive framework is based on real stakeholder data and project survey insights, the ML model was not tested on live OSC projects, nor was a dynamic decision support tool developed as part of this research. Future research may build upon these results by conducting real-world validation in pilot OSC projects or integrating the model into digital platforms used by policymakers and developers.

1.14 Assumptions and Limitations

Assumptions

This study is grounded in several theoretical and methodological assumptions necessary to frame its design and interpretation. First, it assumes that the constructs developed for critical factors influencing Offsite Construction (OSC) adoption, as identified through the global and UK-focused systematic literature reviews, represent the most widely acknowledged factors and constructs in both academic and industry discourse. It further assumes that previous research, such as those by [Goodier & Gibb, 2007](#); [Nadim & Goulding, 2009](#); [Rahimian et al., 2017](#) have tended to treat drivers and barriers as broad, aggregated categories—for example, referencing "cost" as a barrier without disaggregating it into sub-elements such as capital cost perceptions, lifecycle savings awareness, or procurement flexibility. Similarly, terms like "skills shortage" or "limited client demand" are often presented as static constructs, without exploring the nuanced micro-level behavioural, informational, or institutional dimensions that underpin them. Additionally, studies like (Wuni et al., 2019; Wuni & Shen, 2019) had overlap of same factors (like supply chain management) as both drivers and barriers. Failure to drill down on the constituent of such factors creates a lopsided understanding of how such factor drive or inhibit OSC adoption.

By contrast, this study assumes that a more granular exploration—such as differentiating between “protectionism” and “conservationism,” or between “awareness of industry professionals” and “awareness of other industry stakeholders” in human behaviour/attitude or “road width that fits truck size” and “access road that fits truck size” in supply chain logistics are necessary to understand what truly drives or hinders OSC adoption in practice. It also assumes that such distinctions can only empirically surface through well-designed interviews and survey instruments, consistent with the principles of mixed methods inquiry (Fetters et al.,

2013). This study therefore is of the opinion that examining the granular elements is essential for meaningful diagnosis and prediction of OSC adoption influencing factors, like what is observed and done in the medical world (Shiyanbola et al., 2021).

Another key assumption is that the construction professionals interviewed provided authentic and reflective insights grounded in lived and practical OSC experience. This is based on the purposive selection of participants with demonstrated familiarity with OSC, and on the principle of thematic saturation, wherein data collection ceased when no new concepts were emerging -an established approach in qualitative research (Clarke & Braun, 2016; Palinkas et al., 2015).

Methodologically, the mixed methods design further presumes that operationalising qualitative themes triangulated with context-specific SLR into a structured questionnaire format is a valid strategy for quantitatively measuring construct criticality. Similarly, the study also assumed that the survey respondents offered accurate, representative, and unbiased responses, reflecting the broader population of UKCI stakeholders. The survey responses are assumed to be reliable and representative of broader UK industry perspectives, despite the self-reported nature of the data. The study assumes that triangulated findings can be validly translated into structured, quantifiable indicators, and that these indicators are suitable inputs for statistical and machine learning modelling. The choice of algorithms, such as Logistic Regression, Random Forest, and XGBoost, is based on their proven interpretability and performance in prior construction informatics research (Alaka et al., 2019a; Balogun et al., 2024; Egwim et al., 2023; Tixier et al., 2016). It is also assumed that the selected feature selection techniques adequately identified the most critical high-performing predictors in construction adoption modelling without introducing significant bias or noise.

Limitations

Despite the methodological rigour, this study acknowledges several limitations. Identifying and extracting OSC influencing factors was based on existing literature on OSC available up till 2021 and 2024, constrained to English Language articles and specific available database. Consequently, potential relevant non-English or more recent academic and grey literature may have been excluded. Additionally, while the interview phase involved experienced UK construction professional, the sample was limited to twelve participants (with only M&E personnel not included). This may have effect on the transferability of qualitative insights across the entire UKCI.

The predictive modelling approach also faced constraints due to the absence of direct access to nationally or publicly available OSC project datasets. Instead, models were developed using Likert-scale proxy indicators from self-reported project experiences. While robust ML practises such as pre-processing, cross-validation and AUC-ROC evaluations were employed, limitations such as overfitting, class-imbalance and lack of model interpretability remained relevant concerns. Furthermore, the models were not validated in real-world settings, and no live decision support system was implemented. Generalisation thus remained theoretical. Future research should prioritise validation within live construction environment. The researcher also acknowledges self-limitations in statistical expertise and therefore recommends that improvements in statistical analysis be given more attention to in future studies.

1.15 Future studies

This study contributed significantly to understanding and prediction of Offsite Construction (OSC) adoption in the UK. Nonetheless, several research avenues remain open for future exploration. Future research should validate and extend the predictive model developed in this study using live project data across various UK regions and building typologies, including

outside the UK. Also, longitudinal and ethnographic approaches could deepen understanding of behavioural shifts and learning curves among practitioners over time. Comparative studies using alternative adoption theories such as Technology Acceptance Model (TAM), Diffusion of Innovations (DOI), or Normalisation Process Theory (NPT) with other industry frameworks could enrich theoretical insights and test theoretical robustness within different contexts. Further investigation into the readiness of OSC supply chains ecosystem, particularly, relating to construction SMEs and end-users, is also needed for balancing adoption models. Lastly, as digitalisation and data-driven decision-making become central to the built environment, integrating AI, IoT, and BIM technologies into predictive frameworks could support the development of real-time decision support tools or system for OSC adoption.

1.16 Thesis Outline

This thesis is organised into ten interconnected chapters that is built sequentially to address the research aim. As shown in *Figure 1.0*, the chapters explored key Offsite Construction (OSC) concepts, critically review academic and industry literature, theoretical underpinnings, and analytical approaches, examined methodological approaches to identifying OSC influencing factors, and assess the current state of OSC adoption in the UK. The structure reflects the study's mixed methods design, beginning with qualitative exploration and culminating in predictive model development using machine learning.



Figure 4.0: Thesis Outline

1.17 Chapter Summary

This chapter introduced the foundation and focus of a rigorous four-year research study on Offsite Construction (OSC) adoption in the United Kingdom. It discussed the persistent challenges associated with the dominant traditional construction methods and highlighted the benefits OSC offers if more widely adopted across UK construction projects. The concept of OSC was clearly defined for the purpose of this study, followed by a presentation of the research aim, objectives, scope, and guiding research questions. The chapter outlined the key knowledge gaps in current OSC adoption discourse, particularly the lack of theory-informed, prediction-focused, and context-specific studies in the UK. It articulated the rationale for the research and the philosophical stance—pragmatism and critical realism—underpinning the mixed methods design. The methodology involved three systematic literature reviews, qualitative interviews (content and thematic analyses), and a questionnaire survey, leading to the identification of critical influencing factors using a quantitative approach. These factors were used in feature selection and machine learning modelling to predict OSC adoption likelihood. The chapter concluded by detailing the study's contributions to theory, practice, and policy, while also outlining its assumptions, limitations, and delimitations.

CHAPTER TWO

2.0 LITERATURE REVIEW

Chapter Overview

In this chapter, the study reviewed extant literatures for OSC influencing factors from an international context, followed by a review of the approaches (analytical methods and theories) used. Additionally, the study reviewed a UK region specific OSC influencing factors, focusing on the state of OSC in the UK, using RIBA-PoW as a guiding framework. Using content and thematic analysis, the reviews outlined reported OSC influencing factors and their constituent elements, emphasising the elements as the core issues that needs to be addressed in order to achieve wider OSC adoption in the UK and beyond.

2.1 Systematic Literature Review at a glance

The research world is advanced through contributions to knowledge. This comes through inductive and deductive reasonings. By inductive reasoning, new knowledge is added to the existing body of knowledge through interviews, focused group discussions, experiments, new discoveries, among others (Döringer, 2021). The deductive approach contributes to knowledge by examining existing documented knowledge or theories and extending such knowledge or theories.

Further in line with the objectives of this research, one of which is to deduce OSC knowledge, extant literatures were appraised to establish general existing OSC influencing factors from a global perspective (Linnenluecke et al., 2019). Literature review can be conducted and reported in various forms. It can be systematic or non-systematic in structure, and it can be reported

with meta-analysis or not (Schlosser, 2007). Some familiar types of literature reviews are ‘a review or a literature review’, scientometric review, bibliography analysis, critical review, an overview, evaluation, critical evaluations, and systematic literature review. Broadly, a literature review could be a traditional review (narrative) or a systematic review (Charef et al., 2019; Donthu et al., 2021). A systematic review plays a critical role in Evidence-Based practices, research projects and developmental projects (Schlosser, 2006; Straus et al., 2005). A systematic review can be meta-analytic, quantifying effect sizes in multiple extant studies, or meta-synthesizing, offering support or rejection for intervention with strong and sound evidence(s) (Cooper & Hedges, 1994). Since this study sets out to extract commonly identified OSC influencing factors, Systematic Literature Review (SLR) is adopted as the deductive approach owing to its ordered and repeatable search abilities (Cook et al., 1997; Schlosser, 2006) while interview findings was the inductive approach (*See Chapter 5*) for OSC knowledge and construct synthesis.

Systematic Literature Review (SLR) is a tailored, orderly and pre-filtered investigative research review process targeted at synthesising the outcomes of original researches through a rigorous step-by-step approach or strategies that minimises bias to the barest minimum level (Cook et al., 1997; Schlosser, 2007). This step-by-step approach is a scientific method (Petticrew & Roberts., 2006). It focuses on addressing a particular question or set of questions in research. It attempts to observe, identify, examine and generate significant research evidence in addressing the cause it is finding out (Alaka, et al., 2018; Cook et al., 1997). SLR collates a broad amount of literature from database(s) and trims the extant literature down in a systematic manner, using definite exclusion and inclusion criteria known as coding protocol (Schlosser, 2006).

SLR is objective in establishing the boundaries of existing knowledge and research works. This constitutes some of the reasons for its broad applicability in many fields like medicine/health, innovation and adoption, construction, business evaluations and other scientific research endeavours (Schlosser, 2006). Its step-by-step methodology in compiling the plethora of articles to be examined makes its process repeatable, hence affording it excellent reliability and strong recognition in the world of research (Light & Pillemer, 1984; Rosenthal, 1979). Its transparency provides a strong platform for existing research works to be measured in relation to other research works in unveiling deficient or grey research areas that requires further delving deep into (Wuni et al., 2019; Wuni & Shen, 2022, 2020c). Its scientific step-by-step methodology provides powerful tools for reporting existing literature knowledge gaps, which are helpful in redefining future research focus (Eagly & Wood, 1994). In review reporting, SLR helps identify risk factors -possible negative outcome indicators. With all the aforementioned and other known benefits of SLRs, it does not imply SLR is the only reliable approach to literature review reporting. However, its extensive use in achieving trial quality and the integrity of yielded outcomes in medicine (Cook et al., 1997; Schlosser, 2006) has endeared many other disciplines and areas of research to adopt the coding procedure in review analysis (Ehwi et al., 2022; Roberts et al., 2021; Wuni et al., 2019).

The quality of its outcome is dependent on the tenacity and knowledge of the reviewer on the subject being reviewed (Auperin et al., 1997; Moher et al., 1999; Schlosser, 2003, 2006; White, 1994; Whitehead, 1997). SLR can be reported in a number of formats. Examples of such formats are Cochrane Collaboration, Delphi Reporting system, Appraisal-Tools.asp, Preferred Reporting Items for Systematic and Meta Analysis (PRISMA), among others (Drescher & Edwards, 2019; Moher et al., 2007). Some of the mentioned reporting formats have been validated while some are not. One of the validated SLR reporting format is the Preferred

Reporting Items for Systematic and Meta Analysis (PRISMA). It uses a minimum set of items in reporting evidenced based systematic reviews and meta-analysis of research study literature (Haddaway et al., 2022; Page et al., 2021). This reporting framework is designed to address the poor reporting and deficiencies observed in the traditional way of reporting literature review (Egwim et al., 2022). One of such deficiencies include but not limited to inability to repeat review step by step to achieve the result or finding an author claims.

SLR can be time consuming for the initial experts reporting in a field of (new) research (Luckmann et al., 2001; Schlosser & Raghavendra, 2004), because it is very rigorous, requiring strong domain knowledge and strategic documentation skills (Schlosser, 2006). However, the outcome of their works saves a lot of time for other researchers and research works in that area of study or similar related studies (Petticrew & Roberts., 2006). The use of PRISMA has been beneficial in providing the research world with a transformed landscape for reporting literature review protocol (Page et al., 2021).

This research therefore finds SLR an invaluable, reliable and repeatable tool in the quest to extract commonly reported OSC influencing factors for examining wider OSC adoption possibilities- an emerging research subject area within the UK construction industry. The factors synthesized through metadata extraction using systematic literature review were critically appraised using content and thematic analysis.

Examples of SLR research works are Cook et al., (1997) and Schlosser, (2006) research works within the medical field. Cook et al., (1997) reviewed synthesis of best evidence for clinical decisions while Schlosser, (2006) appraised the role of systematic reviews in evidence-based practice, research and development.

Within the construction, engineering and management (CEM) field, Drescher & Edwards, (2019) systematically reviewed transparency in the methods of expert knowledge use within the construction industry research, where the authors advocated for research outcomes using expert knowledge to be reported in formats as transparent as it is usually found when empirical data is used. Alaka et al., (2018) reviewed articles on bankruptcy prediction models of construction firms where the authors provided guidelines for selecting tools that best address distinct firm situation(s). Babalola et al., (2019) employed SLR to examine the implementation of lean practises in the construction industry. Qi et al., (2021) also used SLR to identify emerging technologies in industrialized construction. Mudan et al. (2020) and Wang et al. (2020) employed SLR in unravelling digital technology adoption in OSC. Wuni et al., (2019) and Wuni & Shen, (2020) carried out SLRs in identifying barriers to the adoption of modular integrated construction and critical risk factors in the application of modular integrated construction respectively. Ehwi et al. (2022) addressed the methodologies used in offsite manufacturing research using SLR and critically advocated for the use of other data sourcing means other than quantitative measures in consolidating the existing facts about OSC adoption. Charef et al. (2019) carried out an overview assessment of Building Information Modelling adoption in the European Union.

While this study toes the path of SLR in selecting articles to review, it does not in any way trivialise other non-systematic reviews carried out within the construction industry and relating to OSC in buttressing discussion in some other sections of this thesis. Some of such are the works of Gusmao Brissi et al., (2021) who reviewed factors affecting the use of OSC in multi-family housing provision in the USA, a scientometric analysis by Hosseini et al., (2018) that critically evaluated offsite construction researches, a reviewed literature of technology adoption models and the theories that underlined the novelty of such technologies by Lai

(2017), and reviews conducted to identify drivers and barriers influencing innovation adoptions by Cole, (2017); Correia, (2018); Pan & Pan, (2019) to mention but a few.

Therefore, following the works of researchers who have explored literature reviews in a systematic manner, this study is inspired to explore the factors influencing wider OSC adoption (both from a global context and UK-focused perspective) in a systematic manner to identify the most reported ones and their constituent make up.

2.2 Offsite Construction at a glance

The origin of Offsite Construction (OSC) can be traced back to 1623 when a panelised house was shipped from England to Cape Ann to provide housing for a shipping fleet (Goulding & Rahimian, 2019a). Another account said it was first used 1633, when a Dutch settlement (prefabricated buildings) brought from Holland was built around the Connecticut River (Thomas, 2006). After World War 2, when the returned soldiers demanded accommodation to settle in with their families, these prefab buildings were employed to meet the teeming demands of the soldiers (Thomas, 2006). This indicates that OSC is not entirely a new concept within the construction industry (CI).

It is a revived concept, believed to possess the innovative capability to transform the construction industry landscape positively. It is a prefabrication approach borrowed from the manufacturing industry into construction industry to improve productivity. It is being re-introduced into main-stream construction to address housing shortage, environmental sustainability, net-zero carbon emission, among others. It used to be primarily timber-framed but it has metamorphosed through various advancements, typologies and nomenclatures. Some names by which OSC concept have been known over time are Precast and Prefab methodology of construction, Modern Method of Construction, (MMC), Modular Construction (MC),

Modular Integrated Design (MiC), Industrial Building System (IBS), Pod Construction, Design for Manufacture (DfM), Design for Assembly (DfA), Design for Manufacture and Assembly (DfMA) to mention a few. For the purpose of this thesis, Offsite Construction shall be used to describe the aggregate ‘non-site’ construction works.

While some think OSC is still in at an early stage within the CI, others believe it has grown considering the number of manufacturing companies that have emerged in recent years following its re-introduction into the construction industry (Bain & Wilen, 2024; Goulding & Rahimian, 2019a). What has not been disputed by scholars is its worrisome low-level adoption within the CI (Agapiou, 2022; Blismas et al., 2005; Feldmann et al., 2022; Steinhardt & Manley, 2016; UK Parliament, 2023; Wusu, Alaka, Oseghale, & Oriowo, 2025).

2.2.1 OSC Definitions

Various authors have attempted to define OSC, but the definition have been confined to the scope of their studies. For example, Yan et al., (2018) defined Offsite construction as a prefabrication and assembling technology methodology used to achieve rapid construction. Boothroyd, (1996) defines Off-site Construction as *“a systematic procedure that aims to help companies make the fullest use of the manufacturing processes that exist and keep the number of parts in an assembly to the minimum.”* The CIC Offsite- Housing Review (2013) defined OSC as *‘an approach to process in which the construction value-added on-site is less than 40% of the final construction value at completion’*. It added that *‘Offsite is a construction term to describe a delivery method that adds substantial value to a product and process through factory manufacture and assembly intervention’*. According to (Goodier & Gibb, 2007), Offsite Construction is defined *“as the manufacture and pre-assembly of components, elements or modules before installation at their final location.”* Smith & Quale (2017), described Off-site Construction as the *“...planning, design, fabrication and assembly of building elements at a*

location other than their final installed location to support the rapid and efficient construction of a permanent structure.”

While Design for Manufacture and Assembly (DfMA) has been used in many academic and institutional publications as a term for OSC during early re-introduction of OSC, it is worth noting that DfMA is combination of concepts that enhances OSC concept. DfMA is a hybrid of DfM and DfA concepts. DfM is principally concerned with making individual parts while DfA addresses the means of assembling them (Shang et al., 2019). DfA is associated with cost estimation of assembling products using a well-defined approach; DfM, on the other hand, uses a less structured method to reduce the manufacturing cost of specific parts relating to its uniqueness (Stauffer & Smith, 2005). Both were initially extensively used in the manufacturing of mechanical elements and devices- an industry from which OSC concept was mimicked.

Deducing from the different scholars' definitions of OSC, a striking correlation is that work can be massively ongoing in a factory while site preparation is running concurrently. The installation can be scheduled to be carried out later when the site is ready for work through planned logistics and installation techniques. One of the differing opinions in the definitions is that not all wholistically covered the concept of OSC in a single definition. Therefore, for this study, OSC is defined as mass-producing the construction elements off the construction site or point of use and transporting them to the site/point of use, through a series of logistics, where they are technically assembled through hinging and coupling systems.

Offsite constructions are categorised according to how they are manufactured for use. They are Pre-manufactured 3D Primary Structural Systems, Pre-Manufactured 2D primary Structural Systems (Panels), Pre-manufactured Components (Non-systemised Primary Structure), Pre-manufactured Non Structural Assemblies and Sub-Assemblies, and Traditional Product-led

Site Labour Reduction. (Goodier & Gibb, 2007; RIBA, 2021). OSC parts/components can be built from concrete, timber, or composite materials.

Pre-manufactured 3D Primary Structural Systems: This OSC category is a factory volumetric construction production of three dimensional units under controlled conditions. The production can be fully or partially copulated before final installation on site. Examples include modular rooms, apartment pods, and such.

Pre-Manufactured 2D primary Structural Systems (Panels): This is a flat panel system of OSC walls such as floors, walls, roofs made off site and assembled on site. They range from open panel skeletal frames to closed panel with linings, insulation, doors, windows, and such.

Pre-manufactured Components (Non-systemised Primary Structure): this is the OSC category that uses discrete pre-manufactured elements like columns, beams, staircases, slabs or pile systems that are not part of the broader modular system.

Pre-manufactured Non Structural Assemblies and Sub-Assemblies: this is the OSC categories that describes components members used in OSC buildings and assembled onsite. Examples include bathroom/kitchen pods, utility cupboards, façade systems and MEP modules.

Traditional Product-led Site Labour Reduction: this is the OSC category that enhance productivity and reduce manual labour without full prefabrication. Examples include large-format blocks, pre-sized brick slips, and such.

2.2.2 Factors influencing OSC Adoption

Scholars have worked on Offsite Construction and its adoption in various forms, examining topics such as factors, success factors, critical factors, drivers, barriers, inhibitors, constraints, consideration, opportunities, and such., influencing, affecting, determining, and such. OSC adoption (Azhar et al., 2013; S. M. E. Sepasgozar & Davis, 2018). Some others have taken a broader perspective like influencing factors, adoption strategies, exploration of, as so on to examine how well OSC has been adopted. Their studies outlined various barriers and drivers influencing OSC use (Arif et al., 2017a; Blismas & Wakefield, 2009; Gan, et al., 2018; Gusmao Brissi et al., 2021; Rahimian et al., 2017; Zhai et al., 2014). Some exclusively dealt with the advantages of OSC in a bid to drive its adoption (Andersson & Lessing, 2020a; Blundell, 2020; Shang et al., 2020; Wuni & Shen, 2022), while others have looked at the disadvantages as grounds to disparage its adoption (Brown, 2024; Ridings, 2024).

Many of these scholarly articles have largely identified generalised adoption influencing factors such as cost (Hamzeh et al., 2017), awareness (Goulding et al., 2014), supply chain (Ofori-Kuragu & Osei-Kyei, 2021), and so forth. without detailing the specifics or the constituent make-up of such generalised factors. For instance, these studies reported awareness and perception without breaking such study down into elements like end-user awareness or professionals' awareness ; cost perception or quality perception, to help know what area of the identified general factor may be a probable root cause that needs to be tackled, else, general high-level factors that do not address the real issue/cause would be evaluated. This results in the broad factors being seen as both drivers and barriers or 'redundant' OSC research outcome as described by (Zhang et al., 2021).

However, a few have explored some of the granular critical factors (Pan & Sidwell, 2011; Zhai et al., 2018a). The studies still did not relate how such granular elements constitute the

generalised drivers or barriers. For instance, in an assemblage knowledge study as a limiting factor for OSC adoption, Chao et al., (2007) addressed the use of RFID in component installation and traceability like a stand-alone factor, not noting it as an element of supply chain management or a logistics barrier.

Additionally, some of the reported influencing factors are still found to have both inhibitory and driving impacts on wider OSC adoption (e.g., cost, supply chain management and logistics, (Pan & Sidwell, 2011; Zhai et al., 2018a)). This has left adopters in a debate on the lopsided understanding from the reports on OSC factors, further contributing to low OSC adoption. This confusion is further exacerbated by the absence of an OSC project data repository in the UK to effectively appraise what category such influencing factors or elements belong to (Ridings, 2024; Wusu et al., 2022). This lopsided and overlapping presentations of OSC adoption factors leave adopters confused on how much value OSC will bring to them if adopted.

Further, this study noted that more attention has been given to the production and construction phase of OSC and little or no attention is given to those who want to occupy the building as noted by Wusu et al., (2025), (*See SLR 3*), though some attention seems to be paid to house builders and housing associations providing the buildings (W. Pan et al., 2007a, 2008). While the future of OSC remains a debate within the industry, only a handful of studies has attempted to integrate predictive analytics in their studies to reinforce the positives OSC brings to construction environment and the economy. Studies like (Gan, et al., 2018; Olawumi et al., 2022; Wuni & Shen, 2019) attempted predictive analytic method but they did not focus on relating such to adoption possibilities.

Moreso, no reported study has however combined qualitative insights with advanced predictive analytics to unravel OSC adoption. While partial efforts such as those by Yeyu et al., (2025)

and Olawumi et al., (2022) employed techniques like PLS-SEM in construction analytics, very few, if any, have translated qualitative findings into machine learning-based predictive frameworks for OSC adoption. This gap is particularly significant given calls for proactive, data-driven decision-making in OSC deployment (Zhang et al., 2024). Most studies have either relied on content analysis (count of reported factors from literatures), thematic synthesis or simple statistical models, falling short of capturing the complex, interacting factors influencing OSC adoption in practice (Wusu, Alaka, Oseghale, Yusuf, Sunmonu, Ajayi, et al., 2025; Zhang et al., 2024).

Similarly, not many studies have evaluated the transition from traditional methods to offsite methods in the light of change management (Wusu, Alaka, Oseghale, Yusuf, Sunmonu, & Akinyemi, 2025). This has left loopholes in the efforts concerted at successfully transitioning to OSC. The absence of change management approach seems to have made a lot of efforts go into the technical part of OSC adoption with little attention to some social non-technical aspects. Whereas, transitioning requires a holistic appraisal (Zhang et al., 2024). For example, studies by Wusu, Alaka, Oseghale, Balogun, et al., (2025) and Wusu, Alaka, Oseghale, Yusuf, et al., (2025), using change management tools showed that there is a wide gap between awareness and perception of general end-users and construction industry professionals regarding understanding the workings of OSC.

The current study is therefore grounded in ADKAR (Awareness, Desire, Knowledge, Ability, Reinforcement) and the Concerns-Based Adoption Model (CBAM), offering structured perspectives for analysing both individual and organisational change in the context of OSC. These frameworks guide the interpretation of behavioural and systemic resistance and readiness, rarely explored in combination with predictive modelling techniques. By combining content and thematic analyses findings for SLRs and qualitative interviews with machine

learning algorithms, this study generates both descriptive, predictive and prescriptive insights—bridging a critical methodological gap and contributing to a more actionable understanding of OSC adoption within the UK’s evolving construction landscape.

To address the gaps and challenges from extant literature, this study, within the limits of its aim and objectives, systematically examined the factors influencing OSC adoption from a global and UK-specific contexts, zooming in on the drivers and barriers reported. It also appraised the analytic methods, underpinning theories and any change management tools employed by extant studies. Additionally, it leverage on ML and AI depth to establish the most critical OSC influencing factors and possible model(s) that can help predict the suitability of OSC to the future of UKCI

2.2.3 Machine Learning and Artificial Intelligence Approach to Offsite Construction Adoption Prediction

Over the years, the OSC concept has become well-known in the architecture, engineering, construction, and operations industries, but it has not had a corresponding adoption rate. To know how well OSC can be adopted, there is a need to clarify the drivers and barriers influencing its adoption using strong and detailed analysis, as well as some degree of accurate predictive tools. It is crucial that construction industry stakeholders can identify the key influencing factors on specific construction work and location and how they impact future adoption of OSC. The identified driving and inhibiting factors are evaluated in this study using Machine Learning (ML) to predict favourable features for OSC adoption possibilities on projects.

Machine Learning (ML) is an arm of Artificial Intelligence (AI) that focuses on analysing the dataset provided, developing models from trained and validated datasets and predicting outcomes from the test dataset using identified patterns and trends (McCarthy, 2007). It mimics

the way human beings learn, develops character and operates habitually (Sumana, 2021). It employs algorithms and statistical models to learn from the training dataset (Xie et al., 2020). Machine Learning can be supervised learning, unsupervised learning and reinforcement learning. One of the significant characteristics of ML is the use of a trained dataset to identify a common pattern or trend in the dataset and use such patterns to predict a probable outcome from the test dataset, having finetuned the models developed using hyperparameter tuning. ML has a lot of applications at present and in the future owing to its ability to identify patterns earlier unknown. Interestingly, ML does not need to be outrightly programmed like other computational approaches to identify or predict outcomes (Ryo et al., 2020); libraries of programmes in ML, e.g., Scikit Learn NumPy, Pandas, and Matplotlib, provide the required algorithms.

Some features that put Machine Learning ahead of other analytical tools are its ability to identify patterns or rhythms earlier unknown in data (Martínez-Álvarez & Tien Bui, 2020), the variables options for associating two or more factors, categorisation of factors by similarities, regression analysis, predicting outcomes based on specific criteria, grouping objects or activities based on their history, image recognition, classification as a result of historic observations and structuring unexplored data (clustering). Some popular Machine Learning algorithms include Logistic Regression, Random Forest Algorithm, Decision Tree, Linear Discriminant Algorithm, Naïve Bayes, Support Vector Machine, K-Mean Clustering, Artificial Neural Network and Regression Tree algorithm among others. ***From among this options, the study proposes to establish the best model(s) for establishing critical OSC influencing factors and predict possible OSC suitability for UKCI.***

Machine Learning has been found to be very impactful in automobiles, robotics, language processing, health and finance. More recently, the Machine Learning approach has been tried in some construction research works and has shown impressive positive outcomes. Such ML

research work include Construction Site Safety Indicators (Poh, et al., 2018), Construction Injury Prediction (Tixer, et al., 2016), Bankruptcy Prediction of Construction Businesses (Hafiz, et al., 2015), Construction Activity Recognition Using Sensors and Machine Learning (Akhavian & Behzadan, 2015b). With these positive outcomes, Machine Learning is gradually finding its footing within the construction industry, giving adoption predictability bright hope. Machine Learning, at the time being, is the best-known analytical tool that exists (Olu-Ajayi et al., 2021; Ríos Canales, 2016; Vorobeychik & Wallrabenstein, 2013). It is well known for its ability to predict, forecast, and explore data, including correlation, regression, recognition and classification. Few studies in the past have employed different methods for analyzing Offsite Construction. Such analytical tools used included Nvivo and Analytics Hierarchy Process-AHP Analysis (Sepasgozar & Davis, 2018), Capability, Opportunity, Motivation-Behaviour (COM-B) System (Jones et al., 2016), among others. See Appendix 1.

Even though Machine Learning has been known to be strong in classification and prediction analytics, (Alaka et al., 2019; Olu-Ajayi et al., 2021); to the best of my knowledge, no work has employed the use of Machine Learning to address OSC adoption possibility. Therefore, this research work would take advantage of the high predictability of ML analytical tools in exploring the factors that can foster the adoption of OSC within the UK construction industry

2.3 Systematic Literature Review 1: *Drivers and Barriers Influencing OSC adoption- A global review perspective.*

The purpose of this review is to find out the different commonly reported factors that are influencing OSC adoption from an international context. Further, the review analysis noted likely constituting elements (issues) of such influencing factors as observed from the articles' mentions. This work would later use the identified factors to establish the ones relevant or applicable to the UK through interviews with UKCI professionals. Additionally, the extracted articles were reviewed for underpinning theories and analysis methods used. Overall, the goal of this study is to identify critical OSC adoption factors and use these critical factors make an (near) accurate prediction of OSC adoption possibilities in the (near) future.

2.3.1 Review Approach

To achieve the purpose above, the review was conducted using multiple databases that are popular with SLRs and authors in the area of AECO studies, e.g. [Alaka et al., 2018](#); [Babalola et al., 2019](#); [Drescher & Edwards, 2019](#); [Ehwi et al., 2022](#); [Wuni et al., 2019](#) to mention a few. Such databases included Elsevier's Scopus, Google Scholar, Web of Science, IEEE among others.

Pilot search shows that the word 'OffSite Construction' (OSC) was used in various ways by different authors to convey construction works other than the traditional or conventional method of construction. Example of such authors are [Drescher & Edwards, 2019](#); [Shang et al., 2019](#); [Taylor, 2010](#); [Wuni & Shen, 2020](#); [Wusu et al., 2022](#). This research did not focus on a particular type of construction done off site because not all construction work is solely hinged on a particular approach. Moreover, all the categories of OSC have almost the same approach to construction, except the panellist (2D) form, which takes a closer resemblance to

conventional construction. Related nomenclatures to OSC are, but not limited to, Modular Integrated Design (MiC), Precast Construction (PC), Prefabricated Buildings (PB), Industrialized Building System (IBS), Industrial Housing System (IHS), Pre-manufactured Pre-finished Volumetric Construction (PPVC) among others (Feldmann et al., 2022; Ofori-Kuragu & Osei-Kyei, 2021; Wuni et al., 2019). Design for Manufacture and Assembly (DfMA) and innovative disruption were words closely associated with OSC articles as noted in the SLR pilot search. *See Section 2.2.*

While some school of thought believe that DfMA is a type of OSC (Abanda et al., 2017; Ehwi et al., 2022), other believe it is an approach that aids OSC (Bao et al., 2021; Shang et al., 2019). This study therefore places DfMA as an interface between design and production of OSC components or modules and assemblage. To this end, the search Boolean was thus framed (“Innovation” OR “Adoption” OR “Technology” AND (“offsite construction” OR “DfMA” OR “modular construction” OR “precast” OR “industrial building system” OR “integrated building system” OR “volumetric construction”)). Some exclusion and inclusion criteria were applied to bring down the large number of articles. Such criteria included publication date period, subject area, document type, source type and language. Wuni et al., (2021) lent credence to the date period that extensive shift in OSC research was witnessed only in the last two decades. For instance, some countries are still experimenting with the possibilities and relevance of OSC to their construction market (Nadim & Goulding, 2010) , while others are designing policies for its wider adoption, having seen the benefits of its adoption (Peters, 2024; Zhang et al., 2019b).

The first database searched from the options was Scopus because it has been reported to be one of the largest databases for retrieved articles with excellent interdisciplinary reach (Akhavan et al., 2025; Ametepey et al., 2024). Salam & Senin, (2022) described Scopus as the chief abstract

and reference database of academic papers reviewed by experts, providing 20% more coverage than Web of Science (Umeokafor et al., 2022). It has also been reported to be user-friendly, with wider coverage, easier exclusion and inclusion criteria settings, most indexed articles and an advanced feature for article metrics and citations (Alaka, et al., 2017; Wuni & Shen, 2019). Scopus is also often recommended for construction related SLRs (Owusu-Boadi et al., 2024) because it balances technical and social science coverages (Mongeon & Paul-Hus, 2016), a dimension highly relevant to adoption pursuit of technical and innovation advances in a social setting like OSC case.

The initial input in Scopus returned one thousand and forty-eight (1048) articles. After applying the inclusion and exclusion criteria, the number of articles was trimmed to ninety-eight (98). The 98 articles were published between year 2000 and 2021 and contains over 20% review articles. The SLR commenced in late 2021 after the initial assessment.

Initial search on IEEE using returned six hundred and ninety three (693) articles. Upon applying necessary inclusion and exclusion criteria, the articles were trimmed to one hundred and forty-five (145). Reading through their topics and abstract, it turned out that IEEE did not return relevant articles to the study aim perhaps owing to its specialised discipline for electrical, engineering, computer science and electronics, a limitation that has not endeared interdisciplinary researchers to IEEE (Bramer et al., 2017). Though IEEE has rich articles and some articles from the search would later be useful for discussion in the analysis section, they did not contribute to identifying OSC influencing factors. IEEE was therefore dropped.

Article search was also conducted using Google Scholar (GS)- another rich, broad and interdisciplinary database. GS operate by ranking articles, reporting the most relevant search in the first five to ten pages (Gusenbauer & Haddaway, 2020; Haddaway et al., 2015). Initial

search returned ninety-six thousand (69,000) articles upon applying publication date period. However, further exclusion and inclusion criteria could not be applied due to the structural limitations of Google Scholar (GS), which restrict its use in most academic studies to supporting basic literature reviews rather than systematic ones. (Bramer et al., 2017). This also makes GS lack repeatability, reproducibility and transparency- which are strong attributes of SLR. GS database was therefore not considered for these reasons. Moreover, it was observed that the relevant OSC articles from GS first five pages were indexed also in the Scopus.

Web of Science was another database explored. It is another rich and interdisciplinary search database, but it is subscription-based. Initial search returned five thousand, one hundred and eight (5108) articles. It unfortunately turned out that exclusion and inclusion criteria could not be applied because the school does not have subscription for it (as at the time of this research). The subscription issue also impacted databases like ACSE and Engineering Village. This in itself is a limitation to the study.

Since Scopus provided a handful of articles worth examining, attention was focused on the articles retrieved from Scopus. This approach was buttressed by the research works of Alaka, et al., (2017, 2018); Chen et al., (2010); Malla et al., (2021); Ofori-Kuragu & Osei-Kyei, (2021); Saad et al., (2021a); Wuni & Shen, (2020c, 2020b) who have used Scopus as the main or only literature database in several construction-related research. After the articles were retrieved from the Scopus database, the collated articles were exported to Excel for further scrutiny.

The review report from Scopus search, **Figures 2.1**, affirms that most of the research carried out on OSC within the last 2 decades was actually done in the last 5 years, to be precise. Hence, the study period reflected most current issues relating to OSC adoption globally from the

review. This also reflected the recent technological advancement and innovative disruptive attributes the offsite construction methodology brings to the construction industry globally, which most occurred in the last decade. It would therefore be a sheer waste of effort to consider older papers because the technology reported in some of them may no longer applies to the 21st-century advances made in the construction sector. Moreover, the reviews reported in this research have reviewed the older literatures and reported the most conversant and recent influencing factors from their research.

Over 90% of the articles selected were peer reviewed because it is generally believed that articles that have gone through peer review has been subjected to a high-level of scholarly scrutiny and therefore are of high research quality.

A statistical report of the database is reported in **Figures 2.1.1 - 2.1.3**. **Figure 2.1.1** shows the yearly published articles. The year 2021 reported the highest number of OSC published articles according to the Boolean search. The database indexed articles are cross-cultural even though some reviewed studies are location based. Therefore, the reviewed articles are not geographically biased and have good global representation. **Figure 2.1.2** show the countries from which the articles are drawn.

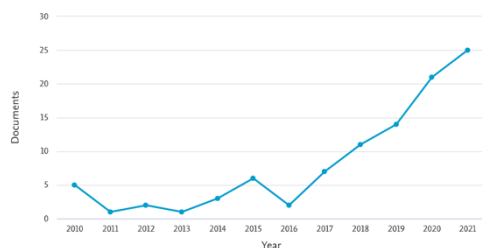


Figure 2.1.1: SLR Documents by publication year

Source: Scopus database analysis



Figure 2.1.2: SLR Documents by geographical location

Source: Scopus database analysis

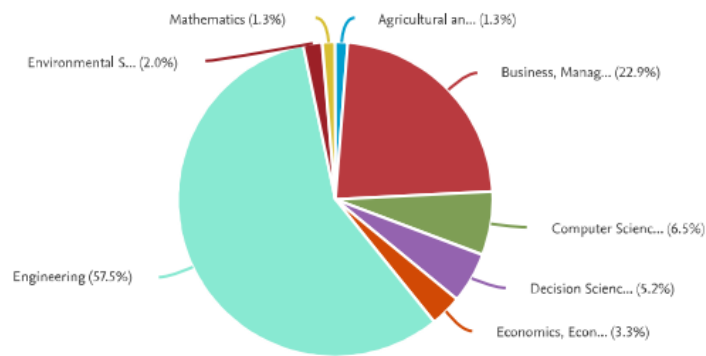


Figure 2.1.3: SLR Documents by subject area

Source: Scopus database analysis

Some of the criteria that the articles that make up the final review articles satisfied are: they discussed offsite influencing factors in the form of barriers or drivers, examined one of the nomenclatures of OSC, and measured these factors from a project-related perspective or otherwise (Saad et al., 2021a). The SLR process flow chart is given in **Figure 2.1.4**.

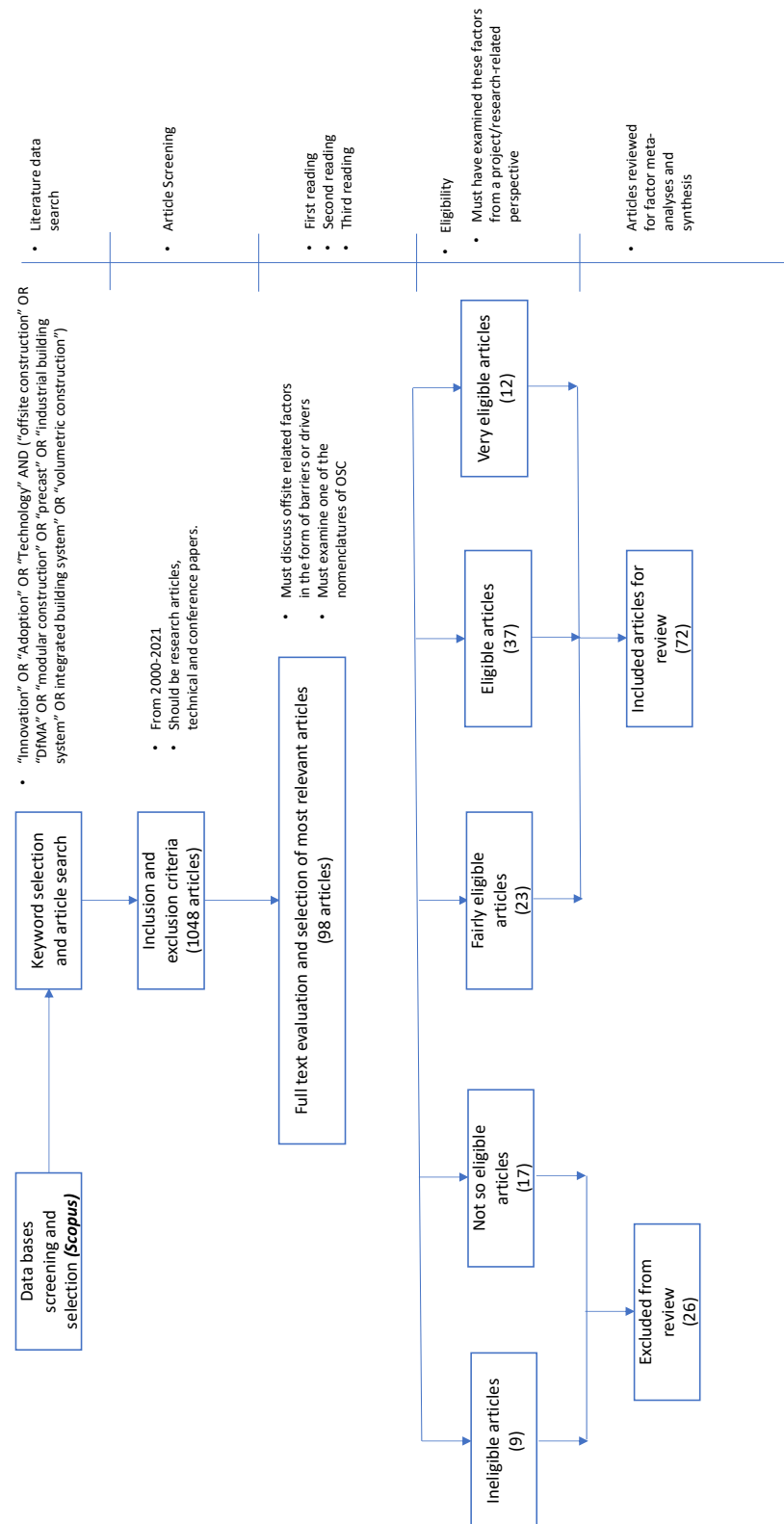


Figure 2.1.4: Systematic Literature Review Process Flow Chart

2.3.2 Data sorting, cleaning and review outcomes

A scoping review was done to set the tone of the SLR (Linnenluecke et al., 2019). The entire 98 articles were read three times. A first cursory reading identified the ineligible articles for exclusion. The second reading eliminated the ‘not so eligible’ articles. The third reading separated the ‘very eligible’ and ‘eligible’ articles from the ‘fairly eligible’ ones. The eligibility criteria the selected articles fulfilled were **they must have discussed offsite related factors in the form of barriers or drivers, must examine one of the nomenclatures of OSC, should be research articles from 2000-2021 (the year SLR1 commenced being 2021), should be technical and conference papers and must have examined these factors from a project/research-related perspective.**

Upon completing review, twelve (12) very eligible articles, thirty-seven (37) eligible articles, twenty (23) fairly eligible articles, seventeen (17) not-so-eligible articles, and nine (9) ineligible articles emerged. It is worth noting that while the twenty-three (23) fairly eligible articles do not satisfy all those conditions of being an article to select, their authors reported some notable factors in most of the introductory part of the articles before veering off into the focus of their research. The said factors were noted among the factors reported. In all, seventy-two (72) articles were evaluated for the critical influencing factors of OSC construction. *See*

Figure 2.1.5

ARTICLE ELIGIBILITY COUNT

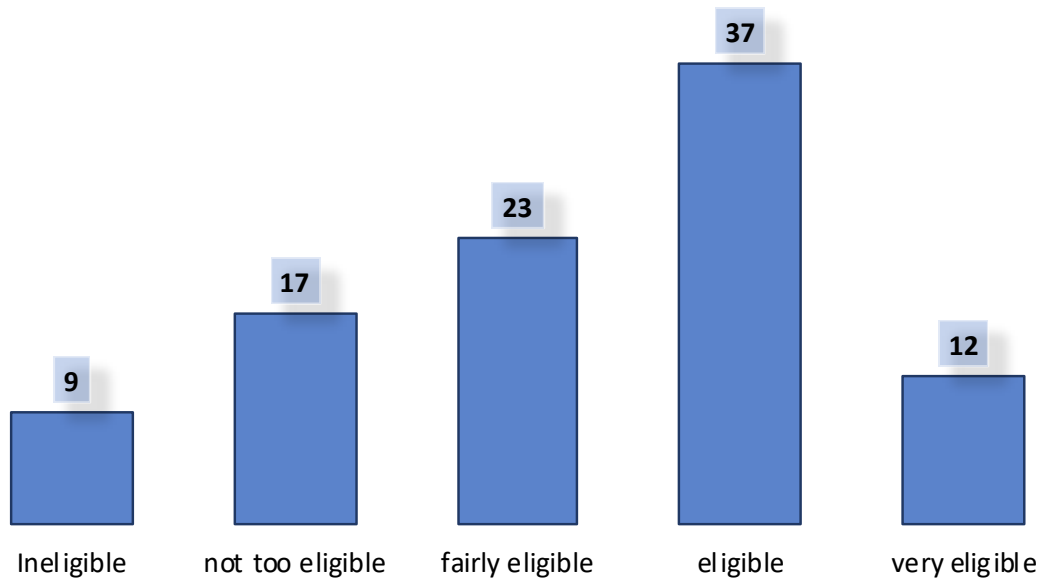


Figure 2.1.5: Count of reviewed articles

Source: Author's own work

An interesting discovery from the SLR was that these OSC influencing factors do not exist in isolation or independently. Most of the identified factors are discovered to be linked to constituent building blocks or make-up elements, which are referred to as ‘issues’ in this study. This is in line with the position of Goulding et al., (2014, p5), on UK’s OSC uptake which noted that “...if OSP (Offsite Production) and manufacturing are to make a positive contribution to society, there is a need to identify the **causal issues** associated with the uptake and adoption of this. This undertaking would need to encompass **several areas**, not least, market drivers and dynamics, culture, societal issues and existing economic business models.”

Upon completing a content analysis, six hundred and twenty-eight (628) issues influencing OSC adoption were extracted. Two hundred eighty-nine (289) of the issues are observed to be drivers and three hundred and thirty-nine (339) barriers. The issues were aggregated into (linked to) the factors they constitute. In all, forty-two (42) broad driving factors and eighty (80) broad barriers were identified, summing up one hundred and twenty-two (122) OSC

influencing factors. Some of these factors are noted to have both driving and inhibiting influencing effects on the wider adoption of OSC. For example, the aggregation identified factors like cost, design and supply chain management (SCM) as barriers and drivers, depending on the evaluated issues constituting them. Some cost-related issues like initial take-off cost and cost of setting up a manufacturing factory are barriers, while long-term cost-benefit and inflation aversion (due to early freezing) are drivers. Similarly, early design freeze is a driver, while the inability to alter or revise a drawing is a barrier. Also, bulk purchase of materials and moving construction activities into the factory are drivers, while the transportation and hedging of modules constitute a barrier. The aggregated factors were further categorised into themes. The idea of commencing the analysis of the SLR from issues through factors to themes provides clarity on the lopsided knowledge of OSC factors, which has been a major obstacle not yet addressed in many OSC adoption reports (UK Parliament, 2023, 2024b). *See Figure 2.1.6*

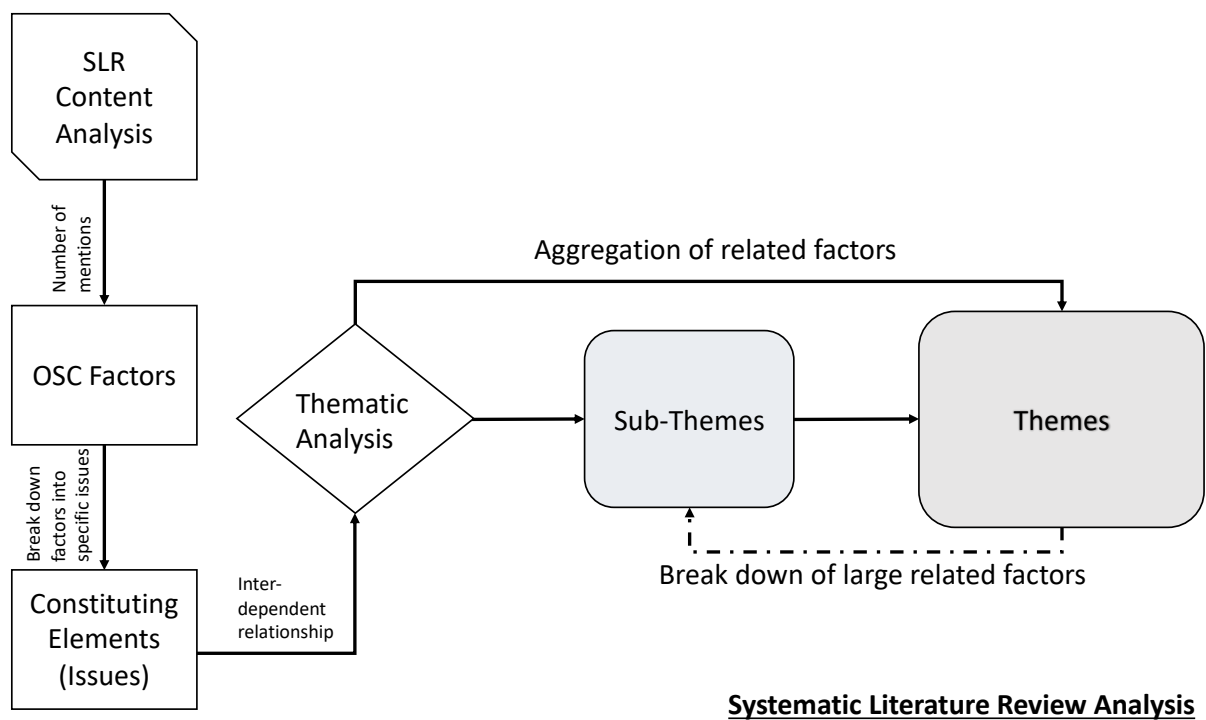


Figure 2.1.6: SLR Notion of Themes

Table 2.1 gives a summary of the observed issues and how they are categorised under broader headings. A few unpopular issues were also identified in the review as contributing to the wider adoption of OSC. Some new issues identified are the length and need of adoption planning strategies (Jin et al., 2018), media influences (Ofori-Kuragu & Osei-Kyei, 2021), adoption promotional regulations (Bendi, 2020a; Jin et al., 2018) among others.

2.3.3 Drivers of OSC

Forty-two (42) OSC broad driving factors were identified from two hundred and eighty-nine (289) driving issues extracted from the seventy-two literatures reviewed. This implies the 289 driving factors constituted elements of the forty-two broad factors. Ten (10) aggregating sub-themes emerged from the factors. These sub-themes are Improved Environmental Impact, Time Saving, Improved Delivery Process, Improved Quality Output, improved HSE and Wellbeing, Improved Productivity, Improved Construction Business Management, Improved Cost Management, Government Policies and Interventions, and Supply Chain and Site management. These sub-themes were grouped into five (5) themes and briefly discussed below.

Table 2.1: Summary of Drivers Identified from SLR 1

S/No	Sub-themes	Sub-Theme Count	Theme	Theme Count
1	Time saving	43	Improved Productivity	140
2	Improved delivery process	39		
3	Improved Quality output	35		
4	Improved Production rate	23		
5	Improved Environmental Impact	65	Improved Environment and Safety	95
6	Improved HSE and wellbeing	30		
7	Improved Construction Business Management	22	Construction business and cost management	38
8	Improved cost management	16		
9	Government Intervention	9	Government Intervention	9
10	Supply Chain and Site Management	7	Supply Chain and Site Management	7
Total		289		289

Improved Productivity: Transitioning from an on-site, labour-intensive construction method into a coordinated and structured factory approach has been reported to add a flavour of productivity to outputs. Borrowing a leaf from the manufacturing industry, the construction industry has increased in efficiency and output by employing a lean approach, high-level consistency, better tolerances in measurements, standardised materials and processes, and trade specialisation (Goulding et al., 2014). With a frequency count of 43, 39, 35 and 23 observed for timesaving, improved process delivery, improved quality output and improved production rate, respectively, the productivity theme ranks as the most discussed driving factor in the systematic review.

The theme indicated that value-added productive transformation to the fragmented conventional construction method (Pan & Hon, 2020a) has increased the construction industry productivity (Zhou et al., 2021a) through the application of production lean practises (Babalola, Ibem and Ezema, 2019; Goh and Goh, 2019, 2019; Omotayo, 2014) time-saving techniques, improved quality output, resulting in enhanced production rate by integrating value-driven production of both prefab 2D and 3D components. The productivity brought about is not limited to project scheduling and factory output only, it extends to supply chain, transportation, delivery and on-site assemblage (Zhai et al., 2017, 2018b). IoT sensors, RFID and tags have been developed to assist the assembly, installation and positioning of the modules or panels rightly and timely. This minimizes probable mistakes that would have resulted in re-works, loss of time, effort and resources (Zhou et al., 2021a). With automation and large machine applications in carrying out tasks, OSC has equally demonstrated potentials to mitigate the waning construction workforce which is a growing challenge within the industry (Nadim & Goulding, 2009) and improve the industry which had hardly grown above 1% globally over the years.

Unlike the rigid sequential waterfall approach largely used in construction project delivery where a task is usually completed and approved before the next can start (Wuni, et al., 2020), OSC allows for some form of agile and overlapping sequences that do not have to depend on an end-to-start sequence of work (Azhar et al., 2013). For constructions, designs are frozen early and shop drawings approved quicker, different building or construction segments and components can be produced concurrently and converged at an agreed state, stage, or time. They are then coupled together to achieve a part of, or the final form to be assembled on site.

Improved Environment and Safety: There is a global call for an improved environment due to the adverse effect climate change is having on the universe (Feldmann et al., 2022). Continual discharge of carbon into the atmosphere is negatively impacting the environment with enormous warming, creating fluctuating weather seasons and health challenges (Babalola et al., 2019). The larger amount of carbon emission released into the environment is traceable to the activities of the construction industry, among other contributors (Singh et al., 2023). The construction industry is reported to be the second largest industry contributing to global warming (Shi et al., 2017).

The acclaimed amount of highly negatively impacting environmental carbon emissions is closely associated with the activities of traditional construction methods both through its embodied and operational carbon-emitting activities (GBC UK, 2019). The global population rise calls for increased housing supply which implies increased construction and infrastructure activities on the depleted environment (Alonso-Zandari & Hashemi, 2017). A probable way to reduce the carbon emission escalating activities is to move the enormous carbon-emitting construction activities into the factory, thereby, improvising alternative and less carbon emitting material and processes (CITB, 2021).

OSC has been advocated to be more environmentally friendly than traditional methods of construction (Jayawardana et al., 2023). Improved health and safety, waste reduction, better environmental performance and sustainability were the most frequent factors observed under Environmental Sustainability and Safety. The articles admit that OSC method reduces construction waste significantly (Lu, Lee, et al., 2021). Construction waste accounts for some of the largest industry waste in the world (more than 40%). The majority of this waste, rather than being recycled or re-used, ends up in the landfill (Osmani, 2012). OSC provides room for re-use, recycling and reduction of waste generated rather than discarding such waste in ways that further degenerate the environment (Babalola, Ibem and Ezema, 2019).

OSC has also been found to promote sustainability which is at fore front of global meetings and agendas. Aside waste reduction, OSC has been found to lower carbon emissions, improve energy efficiency, and encourage deconstructability rather than demolition which creates a great nuisance to the environment (Balogun et al., 2022). Moving construction activities away from the site has reduced disruption to site neighbours (Wuni, et al., 2020), keeps sites cleaner (Wuni & Shen, 2021), and reduces onsite incidents and accidents which have reached all-time high records of death, physical injuries, and emotional trauma to those affected by it and their families (Poh et al., 2018).

Construction Business and Cost Management: Major phases of traditional construction business are regimented around the finish-to-start work approach because the next phase depends upon the previous phase's completion (Wuni et al., 2021a). The industry is equally very fragmented and requires a large pool of interdependent skills which often do not collaborate effectively (Pan & Hon, 2020b). This results in relatively poor management of human and capital resources, slowing down business activities that could have generated better revenue within a short period of time (Boothman et al., 2014; Ngoc Nguyen et al., 2020). This

business approach also makes engaging in technological innovation difficult due to resistance from workers (Andersson & Lessing, 2020a; Lessing & Brege, 2015). Adoption of OSC is poised to quick adjustment in accommodating technological advancement and disruption revolutionising many construction industries globally, give room for modular scalability, enhance collaboration, mitigate inclement weather and produce better processes and products. This positive potentials of OSC would enhance economic and construction industry growth, create opportunities to improve business and project outcomes, and cause minimal negative disruption to construction business.

Rising cost has been identified as one of the major causes of delay, dispute, and litigation within the construction industry business (Pan & Sidwell, 2011; Zhai et al., 2014). Ineffective cost management in construction has been reported as one of the reasons for construction industry's insolvency (Alaka et al., 2017). Construction industry projects are largely associated with huge project financial losses annually. With the construction sector acclaimed to be about the most contributing sector to the GDP of countries, insolvency of construction companies implies loss of jobs and economic downturns (Alaka, et al., 2017). The implications do not end with the construction industries and workers only but extend to the homes and the larger populace. With OSC being characterized by a defined work scope, early design freeze, early and defined procurement, engagement of relevant stakeholders, and reduced project period, a better cost-effectiveness and management structure that would reduce cost is introduced into the project scheme. A quicker and better return on investments (ROI) is therefore promised, if not assured, through reduced customary wastage and inflation aversion.

Government interventions: With advocacy for a greener environment on the rise globally, many world leaders are lending their voices to the adoption of less carbon-emitting activities in the construction sector. For instance, policies are geared to encourage contractors to embrace

OSC and incentives are equally provided to actualise the policies. Furthermore, governments can create national or regional policy mandates and strategic frameworks for public infrastructure and housing like the 25% use on project as recommended by the UK government. Other intervention measures that can be deployed are financial incentives and funding schemes like grants, tax breaks, innovation funding, among others; planning and regulatory support to create quicker pathway for OSC design approvals, public procurement routes as a catalyst, skill development and training, enabling innovation ecosystem among others.

Supply chain management: Supply chain and logistics management is one of the most critical segments of construction projects (Daget & Zhang, 2019). Traditional constructions suffer huge setbacks from supply and logistics shortcomings. Due to tons of different kind of materials needed on site at different stages of the project, delays, mismatch, damage, and losses has been grossly reported on project sites (Daget & Zhang, 2019). Some of the driver benefits OSC adds to the supply chain segment of construction projects are robust and well-established supply chain systems with minimal type and number of materials and component supply, easy traceability of components through use of advanced traceability technologies like chips, RFIDs, geotags and the likes. (Chao et al., 2007a; Wang, et al., 2020). OSC creates the ability to manoeuvre cranes on constrained sites owing to reduced site activities. Also, OSC requires fewer cranes and crane types on site, thereby decreasing conflict-inducing activities (Zhang et al., 2021).

Summarily, from the first SLR, forty-two (42) broad drivers were collated from two hundred and eighty-nine (289) issues observed to be driving OSC adoption from content analysis. These drivers were aggregated into ten (10) sub-themes which were further grouped into five (5) themes discussed concisely above. The most frequently discussed theme driving OSC adoption from the reviewed literature is productivity with timesaving as the most frequently mentioned

contributing factor to productivity followed by improved delivery process and improved quality output. This is in tandem with (Nath et al., 2015; Pan et al., 2008).

According to the review, the second most frequently discussed theme driving OSC adoption is improved environment and safety, with waste reduction as a factor under improved environmental impact being the most highlighted contributing driving factor towards OSC adoption. Other influencing themes with potential to influence the adoption of OSC positively reported in the review are construction business and cost management. Some emerging but salient factors that may further positively influence the adoption of OSC shortly, if critically appraised, are job stability for workers and their well-being, better team management, modular scalability of projects and inflation aversion.

Some of the drivers, when addressed as broad factors without breaking them down into their constituent elements, makes them double as barriers, resulting in lopsided understanding of their adoption influence on OSC. *See Figure 2.1.7.*

2.3.4 Barriers of OSC

The re-emergence and adoption of OSC has faced several inhibiting factors. Extant literature reported these inhibitors in various forms, types, and categories. Some terms used to describe them are barriers (Arif et al., 2017a; Schoenborn, 2012) or risks (Sutrisna & Goulding, 2019a; Wu et al., 2019; Wuni et al., 2019).

This study adds credence to the existing body of knowledge on issues inhibiting the wider adoption of OSC by identifying the nuggets that constitute the building blocks of earlier scholarly identified barriers through SLR. The review, through content analysis, identified eighty (80) broad barriers, having three hundred and thirty-nine (339) issues (constituting elements), as noted from the SLR. The barriers issues were categorised into fifteen (15) sub-

themes before being aggregated into eight (8) themes. Not all the sub-themes could be aggregated; because of the distinctness of some themes; they stood alone, either with a large or low number of factors.

The themes with the most frequently occurring issues constituting major barriers to the wider adoption of OSC are supply chain management, design and construction technology, construction industry management and OSC knowledge and communication, with 82, 72, 57 and 48 mentions, respectively. Other barrier themes are attitude, funding, policies and interventions and environmental sustainability. The barrier sub-themes and themes influencing wider OSC adoption are highlighted *Table 2.2*.

Table 2.2: Summary of OSC Barriers from Literature Review

S/No	Sub-Themes (Barriers)	Sub-Theme Count	Themes	Themes Count
1	Site logistics and supply chain management	82	Supply Chain Management	82
2	Design Issues	29	Design and construction technology	72
3	Structural Performance	23		
4	Technological Disruption	20		
5	Management technicalities	43	Construction Industry Management	57
6	supportive business model	9		
7	Construction Industry Market	5		
8	Communication and Data Management	42	OSC Knowledge, Communications and Data Management	48
9	OSC Knowledge	6		
10	Lack of organisations readiness to transit to OSC	11	Attitude	32
11	User's Perception of OSC	19		
12	Awareness	2		
13	Funding OSC	20	Funding	20
14	Policies, incentives, and Regulations	19	Policies and interventions	19
15	Environmental Sustainability	9	Environmental Sustainability	9
	Total	339		339

Supply chain management: Projects are defined as temporary endeavours with a start and finish date. The effective management of a project is critical to its success (Swarup et al., 2011). Supply chain management is a critical node in the build-up to effective project management amidst other factors like cost, scope, time (Guribie et al., 2022; Mao et al., 2018a). From the selection of procurement route, acquiring material, through transportation and logistics, to delivery, stocking taking and hedging, the supply management determines the timely delivery or failure of project (Zhai et al., 2019a). Supply chain management is a serious challenge in OSC adoption, considering the nature of OSC approach (Wang et al., 2019; Zhang et al., 2021) because OSC project is very reliant on module/component delivery, (hedging or delivery bay/layby) and assemblage. Therefore, failure to organise an effective and manageable production and supply for Just-in-Time (JIT) delivery or proper hedging could spell a doom for the entire project.

Notable among the factors that constitute supply chain challenges to OSC are transportation, production planning and material procurement, the capability of the supplying company, logistics and operation, with 12, 11, 8 and 7 mentions, respectively. Constituting issues associated with supply chain management, as identified from the literature review are hedging strategies, road size regulations, shape and size of the site, access to the site, size and shape of modules, and managing cranes and other heavy machinery on site.

Design and construction technology: Scholarly works described OSC as both disruptive innovation and a revolutionary approach to construction (Tsz Wai et al., 2021; Wuni & Shen, 2019). This implies that OSC does not entirely follow the existing construction paradigms in many ways. Definitions highlighted in this study noted that the design of OSC modules and buildings requires another approach different from the conventional construction drawings (Laovisutthichai & Lu, 2021). The new approach is termed Design for Manufacture and

Assembly, mimicking the manufacturing sector production design approach. A major issue arising from this, according to studies, is that the majority of architects are not versatile in this design approach, thereby inhibiting the wider uptake of OSC. This cascades into other design issues such as defective OSC designs, dimensional conflicts, tolerance issues, long lead time, changes, creativity-lacking designs, compliance failure, among others. (Blismas & Wakefield, 2009; Jaillon & Poon, 2010; Shang et al., 2020; Sutrisna & Goulding, 2019a). Another issue that was noted from the review is that OSC components lack standardization across board (Razkenari et al., 2020). This gives rise to fear of continuity in the case of insolvency of the production company or contractor.

Construction Industry Management: This review indicated management of the construction industry as the second most frequent mention of the barriers inhibiting the wider adoption of OSC with seventy-two counts. The review observed management technicalities, lack of supportive business model and construction industry market with 43, 9 and 5 counts respectively as the sub-themes of this inhibiting theme. The construction industry is laden with many different stakeholders who hold divergent views on how projects should be executed (Tsz Wai et al., 2021; Wuni, 2020). The divergent stakeholders' view makes managing construction activities a herculean task (London & Pablo, 2017; Ngoc Nguyen et al., 2020). The existing traditional model(s) makes it more difficult due to its regimented finish-to-start dominated sequential model. The traditional construction industry business model is defective in fully integrating the OSC method into its practice and policies and so are the planning regulations (Goulding et al., 2014; Pan et al., 2007b) and there seems not to exist a credible business model that comprehensively captures the use of OSC and pre-manufactured solutions.

Moreso, the market structure is dominated by scarce supply to ensure high demand in keeping price values of houses high (Lye, 2020; Rahimian et al., 2017). In a system where global

population has been on continual exponential rise, housing shortages reaching all time demands (Bendi, 2020a; Onososen, 2019), the need to sequence an overlapping approach to close the linear order of the fragmented industry, revise the dominating traditional model and tone down the short supply market system to keep housing prices up has reached an unprecedented imperative (Babalola et al., 2019; Goulding & Rahimian, 2019a).

OSC Knowledge and Communications: Extant studies observed the lack of OSC knowledge and the absence of communication platform(s) as contributing factors inhibiting its wider adoption (Hosseini et al., 2018a; Jin et al., 2018). The present generation of construction industry workforce, many of whom are ageing fast, are quite resistant to learning OSC methodology (UK Parliament, 2024a; Wang et al., 2019). They are also reluctant in providing knowledge and information on developing technologies that would do the work owing to fears of job loss (Agapiou, 2022). Due to the strenuous nature of the industry jobs, the younger generation are not so encouraged to ‘dirty their bodies’ doing energy-sapping tasks (Blismas & Wakefield, 2009; Nadim & Goulding, 2010). The present academic curricula in most higher institutions are reported to only be ‘scratching’ OSC at the surface (Ginigaddara et al., 2021a; Nadim & Goulding, 2009). The advocating bodies thus rely on further education and experimentation to pass the knowledge of OSC across (Darlow et al., 2021; Nadim & Goulding, 2010).

While a handful of literature noted a lack of OSC knowledge as an adoption barrier, some other studies have attributed this lack of knowledge to the absence of records that could provide needed information about proposed or completed OSC projects (Jin et al., 2018; Zhang et al., 2021). Percentages have been provided as a basis for measuring the adoption level as presented by some firms, but these statistical reports have not presented a robust database or datasets from which their inferences have been drawn. While this percentages present some

encouragement on the uptake of OSC as gathering the targeted momentum in line with Construction Industry Council's (CIC) 25% OSC usage, the reality on ground is that this analysis does put figure to the actual number of OSC building projects that make up the percentage.

Attitude: The construction industry has been described to be characterised by an unwillingness to change (resistance) or having a very slow pace (reluctance) to change (Rahimian et al., 2017; Razkenari et al., 2020). The aged workforce is quite resistant to technological advancement (Adeagbo & Oyemogum, 2019). While some of them are evaluated to be open to giving change a chance, the majority of the older workforce are observed to be very 'anti-change'. The resistance to change has been driven through unionism and unwillingness to supply domain knowledge to process improvement ideas and management (Jin et al., 2022; Luo et al., 2020). Another driver of their resistance is fear of job loss (Balogun et al., 2021; Razkenari et al., 2020). They think that automating the industry would take their jobs away rather than thinking automation would give room for them to upskill and improve their values and earning capacities (Ginigaddara et al., 2021a).

Also, the perceived view end-users hold about prefabricated buildings based on earlier experiences and reports has been noted to be contributing to OSC attitude barrier. The majority of those who acquired and used the first set of prefabricated timber houses hold and propagate a negative perception about OSC because of issues relating to leaks, poor material, and weak structure (Gusmao Brissi et al., 2021; Razkenari et al., 2020; Zhai et al., 2014).

The implications of these experiences are resistance and scepticism about the viability of OSC buildings. While CI workers are resistant or reluctant to embracing OSC concept, clients make

stringent requirements on their briefs when OSC is proposed to them. These reveal in low confidence in OSC which further reduce its adoption.

Funding: OSC is a high capital-intensive venture (Pan et al., 2008; Wuni et al., 2019). OSC funding is a cost-capital driven influencing factor. Existing studies has demonstrated that cost plays significant role is how much and how well OSC is adopted (Swarup et al., 2011). While some scholars argue that OSC is more expensive than traditional construction works, others believe that OSC is, in the long run, more cost-effective than traditional construction and that returns on investment are quickly recouped.

Some scholars argued further through experimentation that the difference between the construction cost of OSC structures and traditional buildings is negligible (Hui & Khoon, 2020). The authors also reinforced this position by affirming that the cost benefits of OSC cover up in multiple folds for the small difference in total construction costs. This, therefore, should encourage investors and prospective clients not to sway from funding OSC proposals. Some other cost-related issues influencing the wider uptake of OSC are escalating material and labour costs. This is largely dictated by economic and market forces and can be greatly minimised by early design freeze at the procurement selection phase of the project.

What remains undebated is the fact that a high initial (capital) cost is required to set up an OSC-producing factory (Feldmann et al., 2022; Gusmao Brissi et al., 2021). A good number of scholarly articles that explored barriers to OSC take-off noted initial high cost as a significant barrier (Anvari et al., 2016). This, however, is similar to setting up any other business types. High capital would always be required at the inception stage. What must be borne in mind is that the high initial cost is a one-off cost and what follows thereafter is a running cost. This

also, is a common trend in any business. Therefore, the initial high cost is not a ‘super-peculiar’ case to OSC setup alone.

Another high initial cost observed is the take-off cost at project start phase. Unlike the small fraction of total construction cost that is required for mobilization and preliminary at traditional construction project commencement, OSC, because of its factory-production oriented nature, the need to freeze the design as early as possible, selection of a procurement route for the project and the necessity to mobilize the manufacturing company to commence component and module production, calls for a larger chunk of the project cost to be released at the initial project phase. Some scholars estimated the first release to be as high as 70% as against 15%-20% required for traditional projects (Pan & Sidwell, 2011). Releasing this high amount of finance at a go may be burdening on project investors.

An emerging funding issue also noted from the reviews are difficulties in obtaining financing, mortgages, and insurance for OSC projects and buildings (Ofori-Kuragu & Osei-Kyei, 2021). Also, the component and module nature of OSC manufacturing ‘brands’ it as a ‘product-type’ of construction item. This branding allows it to be transacted cross-country. However, Bendi, (2020) and Ofori-Kuragu & Robert, (2021) observed the trans-border activities related to OSC products also resulted in higher taxes and consequently, higher project cost.

The resultant effect of these cost-capital influencing factor of OSC further leads to difficulty in achieving an economics of scale regarding the adoption of OSC as a methodology, thereby limiting its consideration for project, especially when the long-term effect is not well evaluated.

Policies and interventions: Globally, policies determine and shape what we do, how we do them and what goals organisations and governmental bodies set out to achieve (Lye, 2020; Zhou et al., 2021b). The policies set out dictates what regulations would be outlined, as well

as what interventions and incentives would be required to drive the policies. For instance, the world is, at the moment, faced with global warming and housing shortages. Policies are being developed globally to tackle the rising carbon emissions and housing provision, e.g., Net-Zero Carbon Emission policies that is encouraging everyone to go green.

Construction industry has been reported as a major contributor to global warming (Mahat et al., 2019). Policies are being developed within the construction industry to address the impact of the industry on the issue of global warming (Goulding et al., 2014), e.g., new housing decarbonisation policies. Part of the policies designed is to adopt other measures of construction other than the dominating traditional construction method. This is part of what has led to pushing the idea of OSC on a larger scale aside other potential benefits observed in OSC.

However, not all the policies developed are, at the moment, favouring the wider adoption of OSC (Bendi, 2020a; Zhou et al., 2021b). Existing construction regulations are not yet in consonance with some of these policies. Some of these policies do not support local construction codes (Wuni et al., 2021a). These discrepancies in policy implementation approaches (e.g., policy ambitions vs industry readiness), regulatory incoherence (e.g., planning and building control requirements vs current MMC overlay of Works), among others, are inhibiting the wider adoption of OSC and therefore calls for more intervention in approaching wider OSC adoption.

Environmental sustainability: The rejuvenation of OSC has been largely appraised by extant research works for positively contributing to environmental sustainability (Bras et al., 2020). However, some other scholars hold a contrary view on some of the activities of OSC as negatively impacting the environment. For instance, Wang & Sinha, (2021) reported that the carbon emission and energy required in precast concrete, a form of OSC component, is very

high. The carbon release, air and noise pollution associated with transporting the components to the site is quite enormous. Wang et al., (2020) identified transport as the most sensitive element in logistics and the most contributing to carbon emission in the production of prefab elements.

While green certificates have been earlier appraised as incentive for OSC adoption, few construction companies get issued green certificates for use of OSC on their projects. No non-construction person gets a green certificate or incentive for purchasing a ‘green’ house. There is also lack of standardisation in measuring the environmental impact of OSC and the issuance of green certificates. *(See appendix 3 for full SLR discussions on identified factors/themes)*. The findings are summarised in **Figure 2.1.7** below using Force Field Analysis.

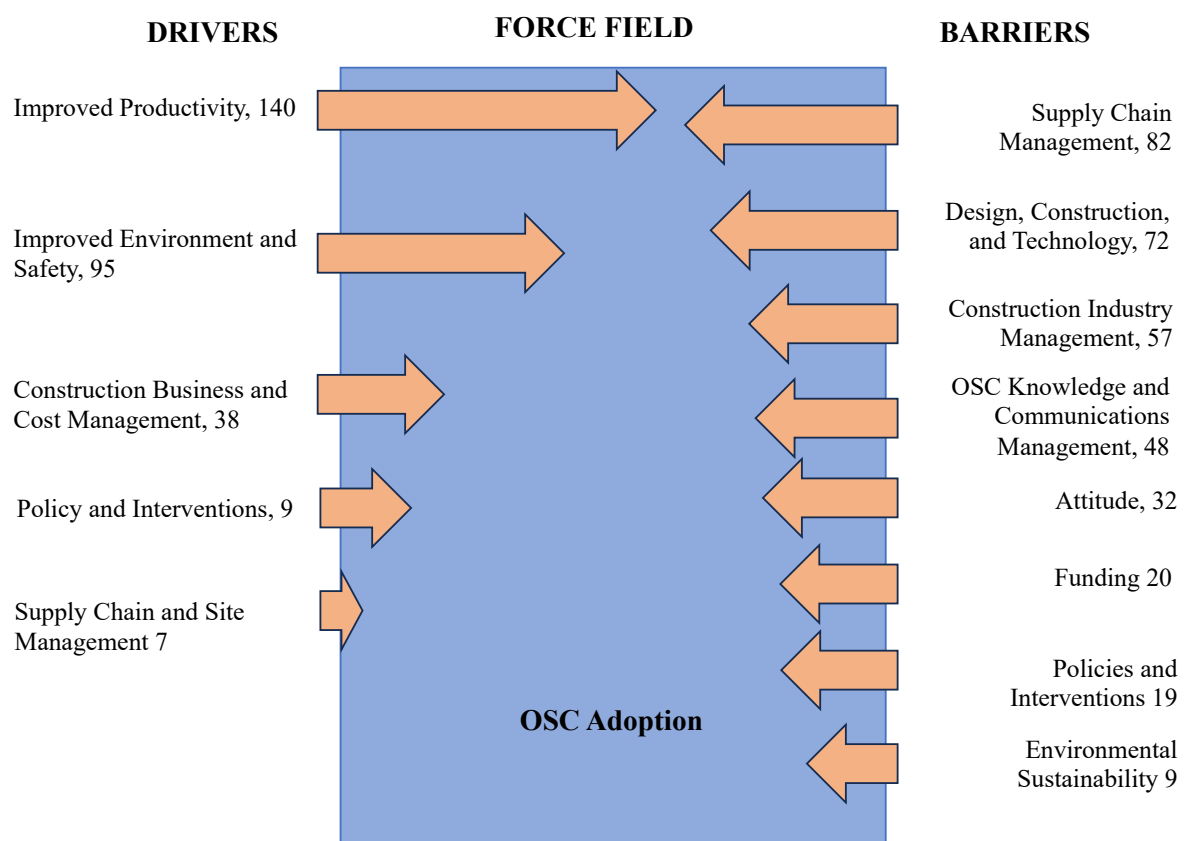


Figure 2.1.7: Influence of Identified themes on OSC adoption according to SLR 1

2.3.5 SLR 1 Summary

Summarily, SLR1 identified one hundred and twenty-two (122) broad factors and six hundred and twenty-eight (628) issues from seventy-two (72) extant articles from a global perspective, as drivers and barriers influencing OSC adoption. The review establishes that the currently reported OSC influencing factors are broad and may not be expressive enough of the real issues determining adoption level, and they also fail to explain the critical factors empirically perhaps due to the study being review (lacking quantitative project metrics) or owing to the analytical methods adopted when it is not a review. This research pattern has resulted in ‘redundant’ research, analysis and identification of (critical) adoption factors as noted by (Zhang et al., 2021). This study therefore establishes that the influencing factors do not exist in isolation or independently but appear to have probable root causes (issues) to which they are traceable. Using the identified issues, the review carefully separated the driver themes/factors from the barrier themes/factors and discussed each theme or factor as either a barrier or driver highlighting the issues that constitute that theme or factor as basis for such discussion.

Also, this review establishes that if the influencing factors are not viewed through the lens of their issues, there is a potential of presenting a lopsided understanding of their influence on OSC adoption, as observed in some extant literature (Goulding et al., 2014; Zhang et al., 2021). The review thus presents a conceptual framework elucidating on the overlap between the driver and barriers influencing OSC adoption and calls for the influence of these factors to be qualitatively appraised (through thematic analysis and categorisation) or quantitatively evaluated from their root causes or issues to enhance the understanding of OSC and to improve its adoption level.

The counts (from content analysis) suggested the important factors influencing the decision to consider using OSC on a project, but the interview will confirm if it is so, and how relevant or

applicable, the frequently mentioned factors are to UKCI while the quantitative analysis will evaluate and affirm the criticality of the observed factors. Also, the ‘important’ factors, from SLR content analysis were merged with ‘important’ factors from interview content analysis to developed hypothetical statements, which were tested with quantitative data.

Moreso, while SLR noted numerous influencing factors and issues, not all apply to the UK. For instance, whereas, supply chain efficiency, number of cranes onsite, waste reduction have been identified as driver issues (*See Appendix 1*); and historical perception, customer satisfaction, seismic effects have been identified as barrier issues , the study cannot tell if these all apply to the UK context, and to what extent until interview were conducted and survey questionnaire administered. This approach followed the recommendation of Wuni & Shen, (2022) and Goulding et al., (2014) who observed that the actual factor(s) that determine the decision to adopt OSC are not independent (and can be made up of conditions and characteristics), and one stage gate may not be enough to decide on adoption or not. Hence, the need for a multi-phase approach and process in identifying the most critical feature(s) from the numerous reported ones. While the granular issues are suggested for quantitative evaluation, the factors broader factors are very valuable for qualitative discussions. *See Figure 2.1.8*

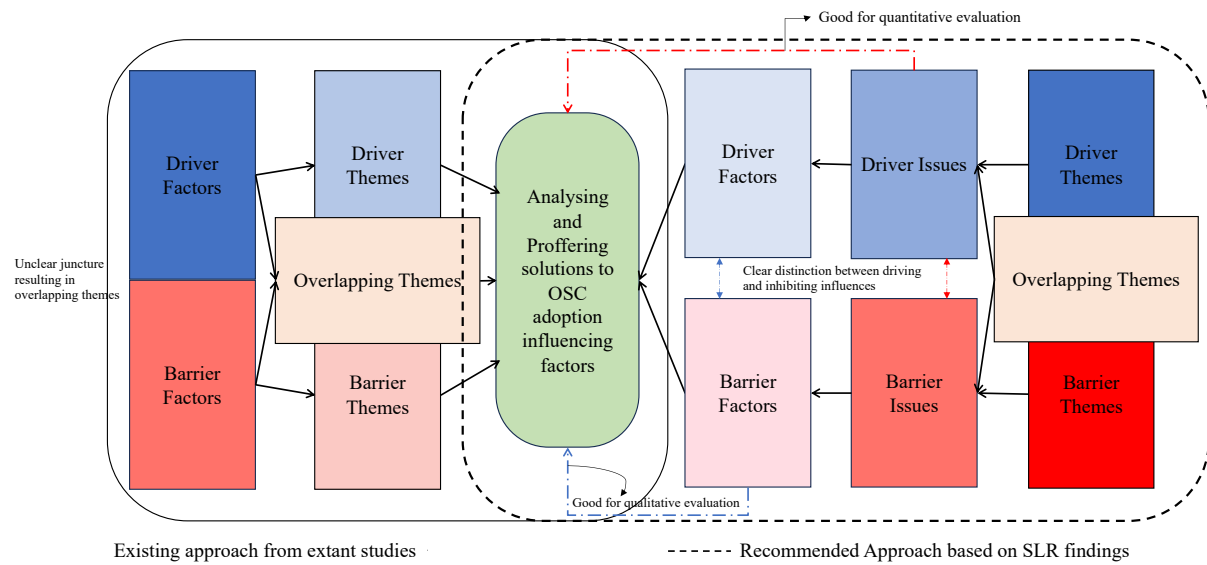


Figure 2.1.8: Conceptual Framework to Approaching OSC influencing factors.

2.4 Systematic Literature Review 2: *An integrative and global review of Analytical methods and theoretical approaches employed in identifying critical OSC influencing factors.*

Different authors have employed different methods and approaches in addressing OSC adoption. While some have looked at factors affecting usage, others have examined what hypothetical approaches can help increase its adoption. For instance, Ehwi et al., (2022) looked at the methodological approach employed in addressing OSC adoption while Blismas et al., (2006) noted on the methods used, arguing that OSC benefits largely depends on project-specific conditions and that the complexities and interdependencies of factors make holistic evaluation a difficult task. This argument appears valid based on absence of project data for rigorous evaluation of OSC adoption decision (Pasquire & Gibb, 2002). What, however, has not been extensively appraised is the analytical tools and theoretical underpinnings guiding literatures on OSC adoption. Blismas et al., (2006) observed that a holistic and methodical evaluation of the applicability of OSC and its acclaimed benefits has been missing in many research works on OSC benefits. Whittemore & Knafl, (2005) recommended studying the theoretical and methodological underpinning of extant qualitative and quantitative articles on a research subject to understand quintessential issues that might have been left unattended to by scholars and to reinforce the need for methods that can enhance decision making on the subject being understudied. Also, Creswell & Creswell, (2018) recommended that the literature review for a quantitative section of a mixed method should relate to major quantitative variables which the study intends to measure and how the dependent and independent variables connects. Therefore, this review relied on an integrative approach to bridge the gap that meta-analytic and traditional reviews do not cover in a given study (Wuni & Shen, 2022) by incorporating an evaluation of analytic methods used in addressing OSC adoption.

The review examined the research approach, analytical method, the project type and the study focus. The study identified sixty-two (62) articles relevant for the purpose of this review from the seventy-two (72) eligible articles extracted in the first SLR. The variation in the number of studies is attributed to the ability and transparency of the authors in reporting explicitly the analytical approach used. The eligibility criteria for this review were articles that stated the research approach, analytical method, project type and the study focus on clear terms or that can be inferred from the published work. While some articles were clear and direct, others are unclear. This occurrence is similarly noted by Plano-Clark et al., (2008) on theory identification using SLR for family science research where the number of articles using theoretical underpinning is less than the number of eligible articles identified for review.

2.4.1 Analytical Approaches Used by Extant Studies

The identified research approaches from the review are Case Study (CS), Experiment (Exp), Experiment with Exploratory Studies (Exp/ExpSt), Exploratory Study only (ExpSt), Mixed Method (MM), Qualitative Approach (Qual), Qualitative Approach with Exploratory Study (Qual/ExpSt), Quantitative Approach (Quant) and Reviews (R). From the eligible articles, the review observed the most used approach for discussing OSC adoption is the Mixed Method Research (MM), followed by the Quantitative Approach (Quant) and then Experimental Studies (Exp). The least used approaches are Experiment with Exploratory Studies (Exp/ExpSt) and Qualitative Approach with Exploratory Study (Qual/ExpSt). *See Figure 2.2.1* below.

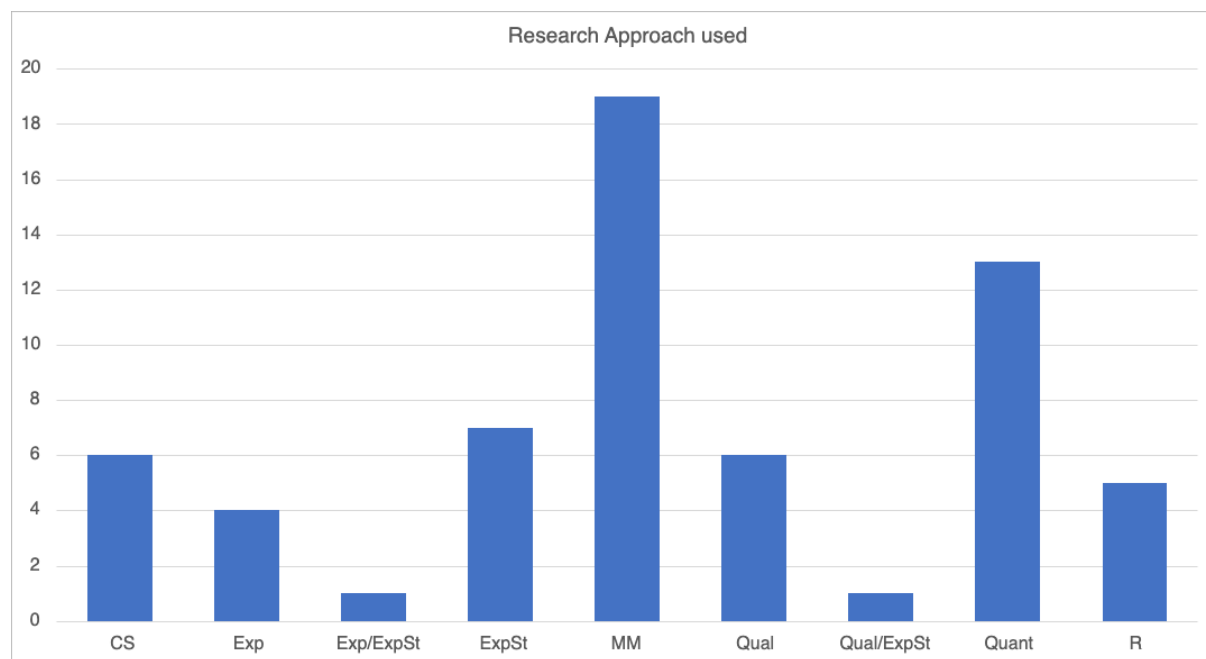


Figure 2.2.1: Research Approaches Used according to Reviewed Articles

Further, the review examined the type of analysis employed and found a range of analysis used in determining the studies' aims. Prominent among the analytical methods used are basic analytics (using the likes of descriptive analysis, reliability analysis, correlation analysis, mean value, Chi Square, Shapiro Wilk test, and so on). A few advanced analytics were also used. They include factor ranking, factor analysis, principal component analysis, and the analytical hierarchy process (AHP). Additionally, there were comparative studies, model simulation, content and thematic analyses, mapping, among others. What is observed not to be much used in the research analyses are change models and predictive analysis in addition to weak, non-organisational focused and non-holistic theoretical anchorage.

Razkenari et al., (2020) used SWOT analysis, Goulding & Rahimian, (2019) used People, Process and Technology (PPT) and Luo et al., (2020) used root-cause analysis. These three are some forms of change analysis approach. Only one study, Jiang et al., (2020), attempted a predictive research. Others that came close to predictive analysis did decision models or multi-criteria decision models (Anvari et al., 2016; Wuni, 2022; Wuni & Shen, 2022) among others.

The review also observed that most studies on OSC adoption focused on buildings (Ismail, 2020; Karthikeyan et al., 2018; Lachimpadi et al., 2012; Lin et al., 2021; Sutrisna, 2018a; Zhu et al., 2018), particularly residential buildings amidst the vast construction branches available within the industry. This suggests the area where most OSC adoption is taking place.

A few other studies explored supportive business models for OSC adoption, (e.g., Andersson & Lessing, 2020a; Goulding et al., 2014; Lessing & Brege, 2015, 2018), arguing that the business models designed for conventional construction methods are not suitable for OSC adoption. Also, only Sutrisna & Goulding, (2019), from the reviewed articles, touched on the ‘occupancy and use’ of OSC building while only Goulding & Rahimian, (2019) touched on ‘people’, that is, ‘end-users’, in addressing OSC adoption. Additionally, only one article Hanna et al., (2016) examined electrical related issues in prefab buildings while no single article examined plumbing (HVAC) related issues. ***See Table 2.3*** for summary of review outcome.

S/No	Authors	Title	Research Instrument (RI) used	RI Code	Analytical Tool used	Project type
1	Rajanayagam H., Poologanathan K., Gatheeshgar P., Varelis G.E., Sherlock P., Nagaratnam B., Hackney P.	A-State-Of-The-Art review on modular building connections	A Review	R	Connection Classification, experimental and numerical analysis methods	high rise MiC
2	Zhang W., Kang K., Zhong R.Y.	A cost evaluation model for IoT-enabled prefabricated construction supply chain management	Quantitative analysis	Quant	System dynamics (A combination of system techniques and analysis) Quite related to ML analysis but does more of relation than prediction	IoT government repository evaluation respect to SCM
3	Wang S., Sinha R.	Life cycle assessment of different prefabricated rates for building construction	Case study, real life project study	CS	Sensitivity analysis	High rise MiC
4	Ofori-Kuragu J.K., Osei-Kyei R.	Mainstreaming pre-manufactured offsite processes in construction – are we nearly there?	Exploratory Literature review and cases studied	MM	Content Analysis, narrative approach, case study; validated with 30 industry reports.	Pre-manufacture offsite process construction
5	Lu W., Lee W.M.W., Xue F., Xu J.	Revisiting the effects of prefabrication on construction waste minimization: A quantitative study using bigger data	Quantitative analysis of 114 sizable Highrise density area.	Quant	Basic statistical Analyses (correlation analysis, t-test, and such), followed by cross-sectional comparison	114 sizable, rise buildings High density area Hong Kong
6	Zhou J.X., Shen G.Q., Yoon S.H., Jin X.	Customization of on-site assembly services by integrating the internet of things and BIM technologies in modular integrated construction	Mixed method research	MM	Interviews, case study	A trial project Hong Kong
7	Bendi D., Rana M.Q., Arif M., Goulding J.S., Sawhney A.	An off-site construction readiness maturity model for the Indian construction sector	Qualitative research approach interpretivism philosophy	Qual	Interviews (15 semi-structured interviews and 5 validation interviews) Content analysis, discourse analysis and actor verification	Indian construction industry and O

8	Yang Y., Pan W.	Automated guided vehicles in modular integrated construction: potentials and future directions	Qualitative research approach (Lit Review, Site Visits and Interviews)	Qual	Scenario Approach (6 iterations)	Automated Guided Vehicles (AGVs)
9	Wuni I.Y., Shen G.Q., Antwi-Afari M.F.	Exploring the design risk factors for modular integrated construction projects	mixed method research (Lit Review, Validation through expert review/interview; survey questionnaire)	MM	Basic statistical analysis (Cronbach alpha test, Pearson, correlation analysis, Mann-Whitney U-test, Shapiro-Wilk test)	No focused project
10	Jin X., Ekanayake E.M.A.C., Shen G.Q.P.	Critical policy drivers for Modular integrated Construction projects in Hong Kong	SLR to identify factors Quantitative approach, positivism (deductive research approach)	Quant	Basic Statistical Analysis for significance (criticality) analysis, exploratory factor analysis,	No focused project
11	Balogun T.B., Awonuga O.O., Abowen-Dake R.	Investigating digital technological competencies amongst Black Asian minority ethnic construction students in the UK	positivism philosophy Purposive sampling Quantitative approach using questionnaire	Quant	Basic statistics using Shapiro-Wilk test and mean values	Black African and Minority Ethnic (BAME) Construction Undergraduate Graduate Students (CUGS)
12	Wuni I.Y., Shen G.Q.	Exploring the critical production risk factors for modular integrated construction projects	Literature review of academic and expert articles, questionnaire survey, exploratory study using quantitative analysis	Quant	Basic Statistical analysis (Cronbach alpha test, mean value for factor severity)	No project
13	Saad S., Alaloul W.S., Ammad S., Qureshi A.H.	A qualitative conceptual framework to tackle skill shortages in offsite construction industry: a scientometric approach	Literature Review	R	Scientometric analysis	No developed qualitative conceptual framework
14	Zhang Z., Pan W., Pan M.	Critical considerations on tower crane layout planning for high-rise modular integrated construction	Multi-method (mixed method)	MM	Interviews and Case Study	High rise MiC

15	Lin T., Lyu S., Yang R.J., Tivendale L.	Offsite construction in the Australian low-rise residential buildings' application levels and procurement options	Mixed method research (Survey questionnaire with 35 professionals and semi-structured interviews with 20 interviewees)	MM	Thematic analysis basic stats using mean value	Low rise p buildings
16	Ginigaddara B., Perera S., Feng Y., Rahnamayiezekavat P.	An evaluation of offsite construction skill profiles	Qualitative research	Qual	Round table discussion, word cloud, ranking data	OSC and constructions
17	Malla P., Xiong F., Cai G., Xu Y., Larbi A.S., Chen W.	Numerical study on the behaviour of vertical bolted joints for precast concrete wall-based low-rise buildings	Experimentation (Numeric)	Exp	Finite element analysis, contact analysis, parametric study, developed a simplified model for predicting shear capacity of bolted joints	Experimental precast concrete
18	Gbadamosi A.-Q., Oyedele L., Mahamadu A.-M., Kusimo H., Bilal M., Davila Delgado J.M., Muhammed-Yakubu N.	Big data for Design Options Repository: Towards a DFMA approach for offsite construction	Exploratory Study using case study	ExpSt	Case study, expert sampling method,	Block of Office
19	Wang Z., Pan W.	A hybrid coupled wall system with replaceable steel coupling beams for high-rise modular buildings	Experimentation (Case study)	Exp	Non-finite Element Analysis	Modular high building
20	Ismail Z.-A.	Lesson learned in maintaining the precast concrete buildings	Exploratory study using case study	ExpSt	Case study	Residential non-residential buildings (8)
21	Bras A., Ravijanya C., de Sande V.T., Riley M., Ralegaonkar R.V.	Sustainable and affordable prefab housing systems with minimal whole life energy use	Mixed method research	MM	MM	Sustainable affordable housing
22	Pan W., Hon C.K.	Briefing: Modular integrated construction for high-rise buildings	Exploratory Technical paper Observations	ExpSt	Systems boundary criteria	High density, rise

23	Razkenari M., Fenner A., Shojaei A., Hakim H., Kibert C.	Perceptions of offsite construction in the United States: An investigation of current practices	Mixed research method	MM	Symposium (unstructured interview), questionnaire, R-studio	Statistical Analysis attempted evaluating level importance of strategy, level impact of challenge, level importance of barrier, important factors considering current 1 drivers, predictability measure of identified factors with basic using mean value
24	Luo L., Jin X., Shen G.Q., Prof., Wang Y., Liang X., Li X., Li C.Z.	Supply Chain Management for Prefabricated Building Projects in Hong Kong	Mixed research method case study, document analysis, interviews Big data by advanced information technology (RFID)	MM	Statistical analysis (scatter plots and line graphs)	production, transportation, assembly applied root cause analysis
25	An S., Martinez P., Al-Hussein M., Ahmad R.	BIM-based decision support system for automated manufacturability check of wood frame assemblies	Experimentation, exploratory study	Exp/ExpSt	Design-Manufacturing process mapping	Design-Manufacturing
26	Wang Z., Wang T., Hu H., Gong J., Ren X., Xiao Q.	Blockchain-based framework for improving supply chain traceability and information sharing in precast construction	Exploratory Study using case study	ExpSt	Process mapping, model development	precast digitalization blockchain technology
27	Daget Y.T., Zhang H.	Decision-making model for the evaluation of industrialized housing systems in Ethiopia	Mixed research method	MM	Analytical hierarchy process (AHP), Decision support system (DSS), Expert choice comparison (ECC), Industrialized housing systems (IHSs), multi-criteria decision support system (MDSS)	Industrialized Housing System

28	Andersson N., Lessing J. (Technical Paper)	Industrialization of construction: Implications on standards, business models and project orientation	Qualitative research on	Qual	Interviews	Precast digitalization
29	Dixon-Ogbechi B.N., Adebayo A.K.	Application of the AHP model to determine prefab housing adoption factors for developers in Lagos State	Quantitative analysis	Quant	Analytical hierarchy process (AHP), Decision support system (DSS), Developers choice comparison (ECC), Industrialized housing systems (IHSs), Sensitivity Analysis	Most Impo building dec factors
30	Wuni I.Y., Shen G.Q., Osei-Kyei R., Agyeman-Yeboah S.	Modelling the critical risk factors for modular integrated construction projects	quantitative assessment structured questionnaire	Quant	Factor analysis (PCA) fuzzy synthetic modelling (check if this is predictive)	OSC (MiC)
31	Jiang W., Wu L., Cao Y.	Multiple Precast Component Orders Acceptance and Scheduling	Quantitative study (predictive in nature)	Quant	Used a heuristic algorithm and a dynamic order acceptance heuristic.	Acceptance schedule develops a pr component acceptance scheduling n to maximize total profit stochastic mu orders environ
32	Yang Y., Pan M., Pan W.	‘Co-evolution through interaction’ of innovative building technologies: The case of modular integrated construction and robotics	qualitative(explorator y) study	Qual/ ExpSt	Content analysis exploratory analysis using case study	Scope: mo integrated construction robotics Measures: s technical transitions technology interaction the
33	Ahmad S., Soetanto R., Goodier C.	Lean approach in precast concrete component production	Exploratory and descriptive	ExpSt	By semi-structured interviews. case study and mapping of the reinforcement work based on time	eliminate previously overlooked

					Lean process application	efficiency of production pro lean production
34	Zhang R., Zhou A.S.J., Tahmasebi S., Whyte J.	Long-standing themes and new developments in offsite construction: The case of UK housing	Review of government policy documents (2004-2019)	R	Bibliometric and thematic analysis	addressing failure of me UK's ho challenge
35	Goh M., Goh Y.M.	Lean production theory-based simulation of modular construction processes	Mixed approach A case study approach, real life project study Interviews Quantitative Analysis	MM	Discrete Event Simulation (DES) Model in Arena Simulation model Mapping Sensitivity Analysis Statistical analysis	Develop a pr baseline for production
36	Zhai Y., Fu Y., Xu G., Huang G.	Multi-period hedging and coordination in a prefabricated construction supply chain	Mixed approach case study, real life study Numerical experimentation	MM	decision models, game theories comparison Numeric analysis (mathematical models)	housing pr construction time
37	Sutrisna M., Goulding J.	Managing information flow and design processes to reduce design risks in offsite construction projects	Case study, archival study Critical realist paradigm	CS	theory-oriented process-tracing, analytical technique, clarification discussion.	2 school pr (one in the UK one in Australi
38	Sutrisna M., Cooper-Cooke B., Goulding J., Ezcan V.	Investigating the cost of offsite construction housing in Western Australia	Case study Archival Study Critical realist paradigm	CS	Comparative data analysis	Residential
39	Wuni I.Y., Shen G.Q.	Towards a decision support for modular integrated	Integrative review (SLR)	R	stage gate approach Content Analysis	MiC

40	Wuni I.Y., Shen G.Q.P., Mahmud A.T.	Critical risk factors in the application of modular integrated construction: a systematic review	Exploratory study- A qualitative research design systematic literature review	Qual	Thematic-Content Analyses	MiC
41	Sutrisna M., Ramanayaka C.D.D., Goulding J.S.	Developing work breakdown structure matrix for managing offsite construction projects	Critical realist paradigm Archival Study of cases Discussion	CS	WBS-Matrix	Case 1: volumetric classroom mo Case 2: s building (sn nursery bui and the secondary classroom buil no detailed provided
42	Zhai Y., Zhong R.Y., Huang G.Q.	Buffer space hedging and coordination in prefabricated construction supply chain management	Literature Review	R	Game approach, model comparison, model development Comparison analysis Numerical study	Buffer hedging Supply coordination
43	Karthikeyan V., Vinodhini E., Aparna P., Monika T., Kumar R.S.	Study on comparison between prefabricated and conventional structures	Quantitative Research	Quant	Literature review Comparative cost analysis	single and m storey resid buildings G+7 storey ho board co building
44	Zhu H., Hong J., Shen G.Q., Mao C., Zhang H., Li Z.	The exploration of the life-cycle energy saving potential for using prefabrication in residential buildings in China	Mixed approach case study, (Scenario-based) Quantitative study	MM	I–O analysis (Higher order analysis) Process-order analysis Hybrid Analysis	Scenario based and pr constructed building wit energy compl measures Case study prefab buildin Chengdu Shenzhen, Sic

45	Yuan Z., Sun C., Wang Y.	Design for Manufacture and Assembly-oriented parametric design of prefabricated buildings	Comparative/Exploratory study	ExpSt	process improvement mapping	Design Software
46	Arashpour M., Bai Y., Arandamena G., Bab-Hadiashar A., Hosseini R., Kalutara P.	Optimizing decisions in advanced manufacturing of prefabricated products: Theorizing supply chain configurations in off-site construction	Exploratory study using case study	ExpSt	three research hypotheses on optimization of supply decisions and configurations are developed and tested	Real-world precast panel production project
47	Zhai Y., Zhong R.Y., Li Z., Huang G.	Production lead-time hedging and coordination in prefabricated construction supply chain management	quantitative analysis	Quant	decision models, comparative cost analysis	Supply management site hedging Prefab house-life project
48	Savoia M., Buratti N., Vincenzi L.	Damage and collapses in industrial precast buildings after the 2012 Emilia earthquake	Mixed approach, (discussion and case study)	MM	Ground motion analysis	prefabricated industrial buildings
49	Hanna A.S., Mikhail G., Iskandar K.A.	State of Prefab Practice in the Electrical Construction Industry: Qualitative Assessment	Quantitative study	Quant	Statistical analysis (Chi Square)	No focused projects
50	Hamzeh F., Ghani O.A., Bacha M.B.S., Abbas Y.	Modular concrete construction the differing perspectives of designers, manufacturers, and contractors in Lebanon	Mixed method research (case study and face-to-face structured interviews, survey analysis)	MM	Basic statistical analysis	Lebanese Precast concrete firms
51	Anvari B., Angeloudis P., Ochieng W.Y.	A multi-objective GA-based optimisation for holistic Manufacturing, transportation and Assembly of precast construction	Quantitative study with case study	Quant	Genetic Algorithm-based (GA-based) searching technique	Manufacturing transportation Assembly (all sectors of precast construction projects)

52	Xiao J., Ding T., Pham T.L.	Seismic performance of precast recycled concrete frame structure	Experimentation (Case study)	Exp	Wen Chuan wave (WCW, 2008, N-S), El Centro wave (ELW, 1940, N-S), and Shanghai artificial wave (SHW) were selected as the input seismic waves, in the order WCW → ELW→ SHW during the test process.	a six-story precast recycled aggregate concrete (RAC) space frame structure
53	Goulding J.S., Pour Rahimian F., Arif M., Sharp M.D.	New offsite production and business models in construction: priorities for the future research agenda	3	3	The inferential analysis of variance (ANOVA) methods	People, Processes and Technology
54	Nath T., Attarzadeh M., Tiong R.L.K., Chidambaram C., Yu Z.	Productivity improvement of precast shop drawings generation through BIM-based process re-engineering	3	MM	Surveys, interview, workshop and experiments	A precast façade system: an example
55	Demian P., Walters D.	The advantages of information management through building information modelling	Mixed research	MM	hierarchical information paradigm	4 different factors
56	Abedi M., Rawai N.M., Fathi M.S., Fathi M.S., Mirasa A.K.	Cloud computing as a construction collaboration tool for precast supply chain management		UD		
57	Khalili A., Chua D.K.H.	IFC-based framework to move beyond individual building elements toward configuring a higher level of prefabrication		UD		
58	Lachimpadi S.K., Pereira J.J., Taha M.R., Mokhtar M.	Construction waste minimisation comparing conventional and precast construction (Mixed System and IBS) methods in high-rise buildings at Malaysia	case study	CS	Quant approach, (mathematical) analysis	High rise buildings, medium cost rise residential buildings

59	Pan W., Sidwell R.	Demystifying the cost barriers to offsite construction in the UK	case study	CS	Basic statistical analysis (correlation analysis) Cost comparison analysis	20 medium-to rise resid buildings of projects by leading housebuilder OSC and constructions
60	Jaillon L., Poon C.-S.	Design issues of using prefabrication in Hong Kong building construction	Mixed method research (questionnaire survey and case studies)	MM	Basic Statistical analysis (mean value and standard deviation for factor severity)	high rise resid buildings
61	Sacks R., Kaner I., Eastman C.M., Jeong Y.-S.	The Rosewood experiment - Building information modeling and interoperability for architectural precast facades	Experimentation (Case study)	Exp	3D Model design comparison	16 story c building
62	Polat G.	Precast concrete systems in developing vs. industrialized countries	quantitative Study (questionnaire)	Quant	Basic statistical analysis	Precast Concre
63	Chen Y., Okudan G.E., Riley D.R.	Sustainable performance criteria for construction method selection in concrete buildings	Mixed method research (questionnaire survey, case study (7), interviews and site observations)	MM	Ranking analysis factor analysis	Prefabrication on-site constru method,
64	Kale S., Arditi D.	Innovation diffusion modeling in the construction industry	Mixed method research (survey data and 2 case studies)	MM	uses the nonlinear least-squares method, uses the dominant-less dominant analytical method	Construction industry

The review also observed the absence of industry guide in OSC adoption research works. Using the RIBA Plan of Works (RIBA-PoW), which is the single work guide for all construction related activities in the UK as a framework, this study examined the relevant articles researched areas under the RIBA-PoW lens. The RIBA-PoW comprises eight stages namely Strategic Definition-Stage 0, Preparation and Briefing-Stage 1, Concept Design-Stage 2, Spatial Design-Stage 3, Technical Design- Stage 4, Manufacturing and Construction- stage 5, Handover-Stage 6 and Use-Stage 7 (*See details in Section 2.5*). It emerged that stage most researched stage is the RIBA-PoW Stage 0 (Strategic Definition, Stage 0, 28 counts), followed by stage 5 (Manufacturing and Construction, Stage 5, 26 counts). The least explored areas are Handover and Use (Stages 6 and 7). (*See Figure 2.2.2 and See Appendix 3*). *This study later compared UK-focused articles researched areas under the RIBA-PoW.*

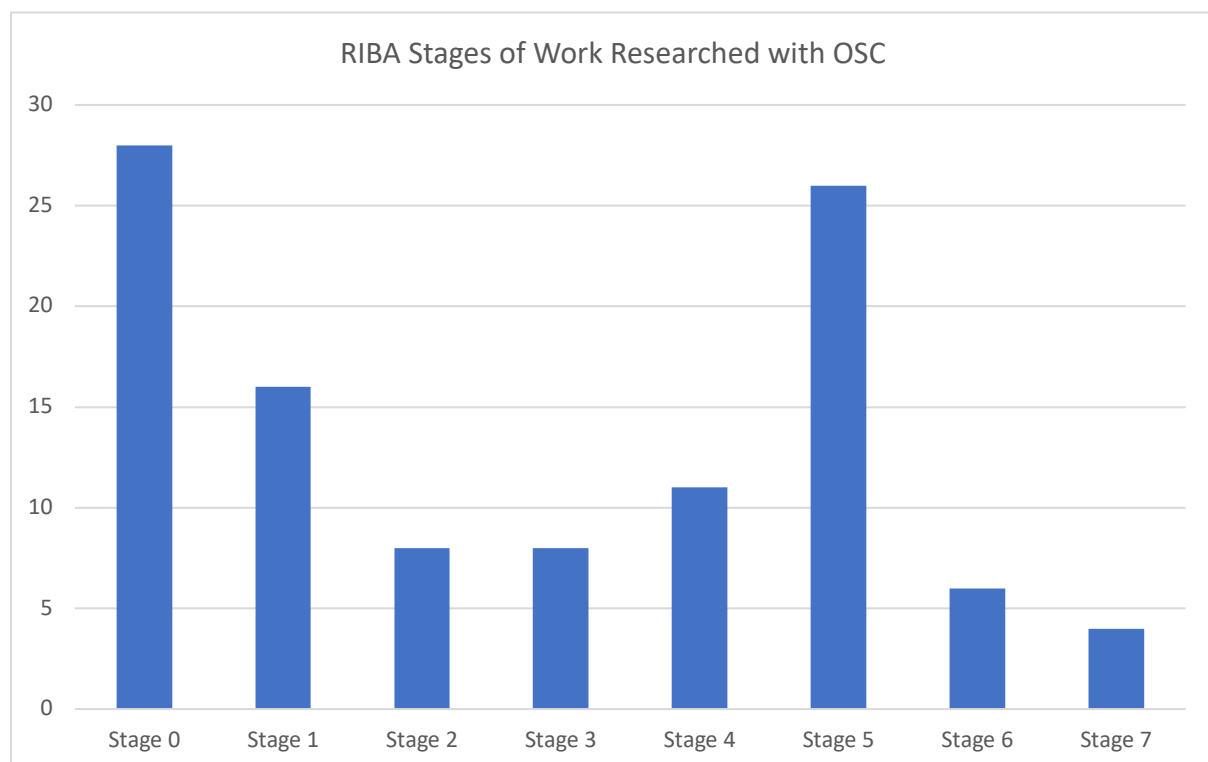


Figure 2.2.2: RIBA-PoW stages Explored according to reviewed articles

2.4.2 Theoretical underpinning

The review also appraised the theoretical underpinning that guided the studies. The analyses show that seventeen articles (27%) used theoretical underpinning for the research work while 47 (73%) articles did not base their studies on any theory (*See Chapter 3*). Also, 25 articles (42%) developed theoretical/conceptual frameworks/models for studies their while 35 articles (58%) neither developed theoretical frameworks nor conceptual models for their studies. *See Figures 2.2.3 and 2.2.4.*

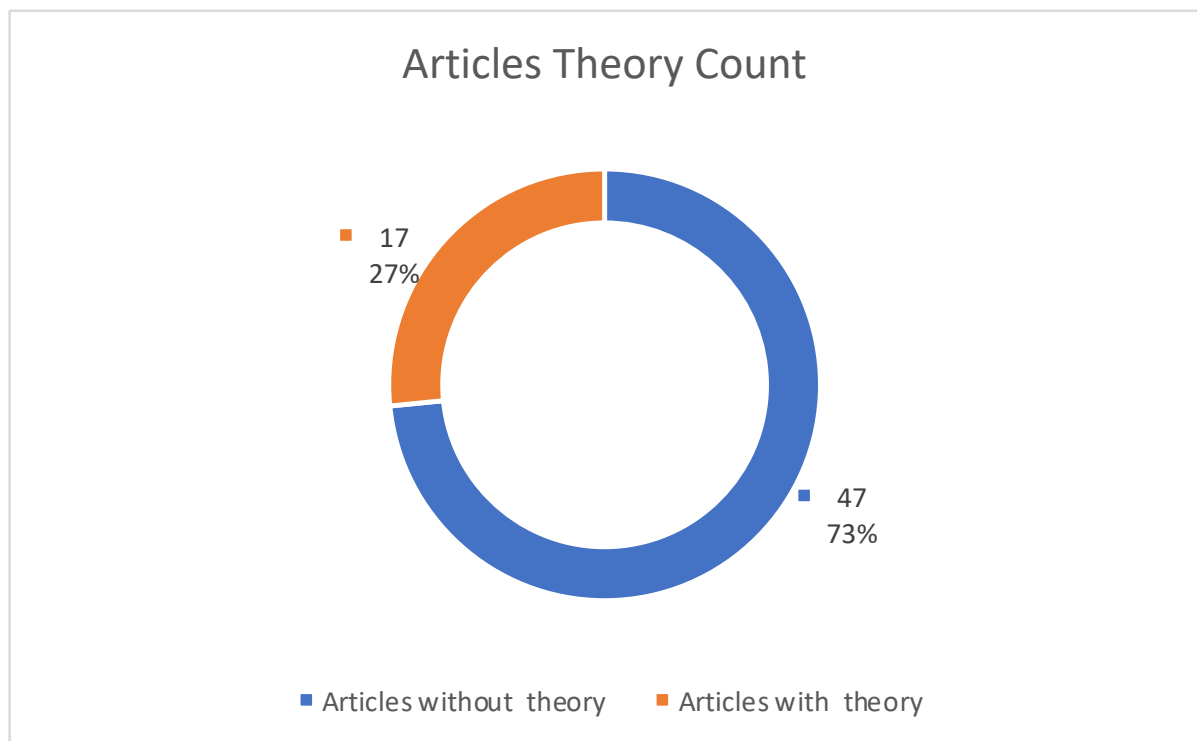


Figure 2.2.5: Articles Theory Count

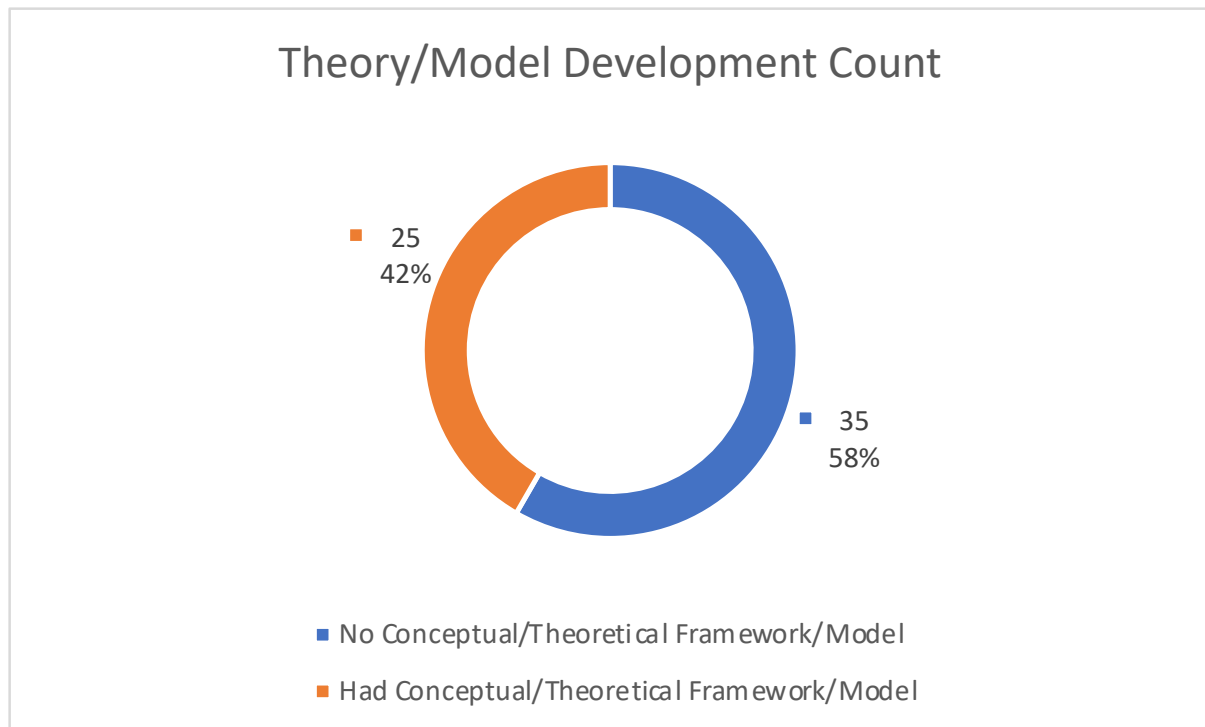


Figure 2.2.4: Theory/Model Development Count

A few studies, precisely nine from sixty-four articles (Ahmad et al., 2019a; Daget & Zhang, 2019; Goh & Goh, 2019a; Khalili & Chua, 2013; Sacks et al., 2010; Wuni et al., 2022; Yang et al., 2019; Zhang et al., 2021a) had theoretical underpinning and also developed conceptual/theoretical frameworks or models for their studies. This finding agrees with studies that have reported the dearth of theories in construction, engineering, and management studies, highlighting this limitation as one of those influencing wider adoption of innovative technologies within the industry.

2.4.3 SLR 2 Discussion and Recommendation

While these approaches may have addressed the research aims of their authors and provided OSC adoption discourse with some insights, they often exhibit some form of disconnect on the findings of quantitative and qualitative insights. Additionally, they fail in triangulating these findings in recommending pathways to wider OSC adoption. Moreso, only a few of the studies

go beyond basic classifications to applying predictive analytics, use of ensemble models or rigorous feature selection techniques based on construction data in addressing OSC adoption. The use of basic and statistical models also limits adaption to evolving context and data aside not responding to or fully capturing hidden, non-linear or interactive effects like perception or market readiness among other OSC influencing factors.

Again, noting the fragmented and diverse nature of the construction industry as still largely impacting the OSC adoption level, just a type of research approach may not be sufficient to address the low adoption state of OSC, and may not meaningfully determine the very critical factor truly accounting for the low adoption state. Therefore, this research presents the need for a more holistic approach to viewing, appraising and evaluating OSC adoption beyond a ‘face’ value approach.

To begin, this study proposes a conceptual framework (*See Figure 2.1.8*) to addressing OSC adoption challenge following findings from the reviews. This framework should be adopted with caution as it only lays the foundation for other researchers to build on or apply to their country, region or context situation. Also, this review found there is little attention to end-users and house builders. It therefore calls for more research to be carried out on these adopters as they are the consumers of the product, and they, to a large extent determine how well OSC would be adopted (Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025; Wusu, Alaka, Oseghale, Yusuf, Sunmonu, & Akinyemi, 2025). If they do not accept OSC ‘product’, adoption may stay low irrespective of how much research is invested in other areas within the CI. This study also recommends exploring analytical approaches that include change management, product management, and business-analytics approach to addressing OSC adoption among others as these drills down to specific issues influencing adoption.

2.5 Systematic Literature Review 3: *A state-of-the-art Review for OSC influencing factors- Using RIBA PoW*

The initial SLRs articles were extracted without restriction to geographical location to give a global perspective on OSC adoption influencing factors. The identified factors from the review were taken to industry professionals in the UK to affirm the relevance of these factors to the UKCI and appraise their criticality to OSC adoption in the UK. However, to consolidate the outcomes of the first and second SLRs and the findings from the interview, a third SLR was conducted to understand how the themes observed from SLR1 may relate with the UK RIBA-PoW and how understanding this reflect the state of OSC within the UKCI and guide operationalising the survey questions developed.

As noted earlier, the RIBA-PoW is the main guide for construction-related practices in the UK (Sutrisna & Goulding, 2019a), (*See Section 2.4.1*). It is described as the ‘de facto’ standard framework that determines how construction projects are run in the UK from inception to completion (Phillips, 2008). The framework organises the work process into 8 stages (RIBA, 2024). RIBA-PoW stages are highlighted below:

Stage 0 (Strategic Definition): Stage 0 involves selecting a construction method aligned with project goals, advising on the optimal supply chain, and defining the project’s aim, performance specs, and procurement plan. It also entails confirming this strategy, assessing cash flow impacts from various MMCs, and considering factors such as business case, deadlines, funding, indemnity, risks, design team constraints, legislation, system logistics, and project scope.

Stage 1 (Preparation and Briefing): At this stage, the project brief is developed and pre-design studies conducted. This stage validates the procurement strategy, assess cash flow effects of

MMC options, and establish design partner competence criteria. It also addresses site logistics, supply chain capacity, building type fit, procurement challenges, cost-time-quality trade-offs, sustainability targets, digital implementation, handover plans, and the appointment of the design team and specialist manufacturers and suppliers.

Stage 2 (Concept Design): This stage advances design consideration aligning developed design concepts with the brief and initial sustainability goals, focusing on spatial constraints, MMC selection, site conditions, procurement, manufacturer availability and factory capacity.

Stage 3 (Spatial Coordination): Stage 3 finalises spatial arrangements and coordinates design elements. It aligns architectural and engineering plans, revises construction strategies and cost plans, and evaluates buildability, sequence, fabrication, and warranty provisions for MMC systems.

Stage 4 (Technical Design): The stage gathers all necessary design details for manufacturing and construction, considering DfMA relationships, connector systems, environmental barriers, and prototyping within design constraints.

Stage 5 (Manufacturing and Construction): Stage 5 focuses on factory production, site assembly, and commissioning, with design work halted and construction strategy updated to include logistics, module handling, and quality control.

Stage 6 (Handover): This stage finalises the building contract, transfers property ownership, initiates aftercare, and collects feedback to improve future projects.

Stage 7 (Use): This is the operation and maintenance evaluation phase, with performance and feedback informing future projects. This stage tracks component performance and replacement,

and strategies for re-use, recycling, or removal at end-of-life, enhancing OSC use and adoption.

This review aims to understand the stages and works that have been well covered in the RIBA-PoW framework by UK-focused academic research and the stages and areas that require more research work to improve OSC adoption in the UK.

Following the rejuvenation of OSC in the UK, there is need for MMC compliance with existing building regulations, especially the RIBA PoW. However, no known study has evaluated the influence of RIBA-PoW on OSC adoption process. The current RIBA framework does not encapsulate the process of work that MMC follows. For instance, a floor slab stage work in traditional construction is not present in module installation. For reasons such as this and many others, the current RIBA plan of works was overlaid with a Modern Method of Construction (MMC) practise work system to ensure it conforms with the UK construction guide (RIBA, 2021) owing to some of the limitations highlighted in SLR 2, rather than having to create something entirely new for MMC. The overlay was described as Design for Manufacture and Assembly (DfMA) overlay of works (RIBA, 2021). This is crucial to OSC adoption pursuit because it gives room for accountability of the disruptive nature of MMC, ensures standard practise, improve MMC design approval process among others.

The findings from the review therefore considered the Design for Manufacture and Assembly (DfMA) overlay of works framework (adopted for MMC/OSC works) alongside RIBA-PoW in appraising the RIBA-PoW influence on OSC adoption, even though both frameworks look quite similar. *See Figures 2.3.1 and 2.3.2.*

The review therefore achieved its purpose by:

- i. Systematically examining UK-focused literature for areas that have been reported explored in pursuit of OSC wider adoption, identifying such areas of focus reported in each article.
- ii. Identified and classified the focus areas of OSC adoption process in extant studies using RIBA PoW and Design for Manufacture and Assembly (DfMA) overlay of works.
- iii. Overlay the findings with RIBA plan of work and Design for Manufacture and Assembly (DfMA) overlay of works to find area requiring more inputs.

Key review questions addressed are:

- i. What OSC adoption process areas are most discussed in the articles?
- ii. What areas of OSC adoption have been explored when examined under the RIBA plan of works' lens?
- iii. What category under the RIBA plan of work can the explored OSC adoption areas be classified?
- iv. What areas require more inputs to improve the current adoption state?

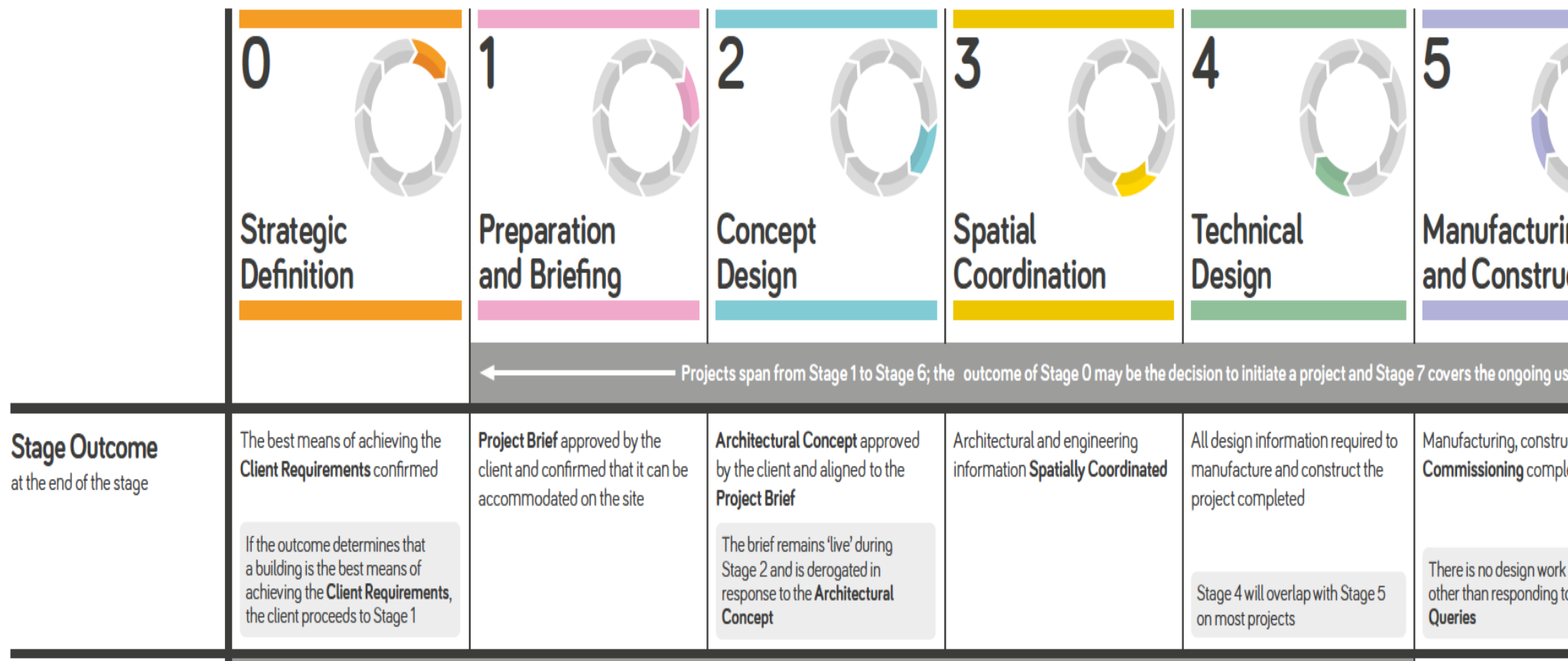


Figure 2.3.1: RIBA POW overlaid with DfMA PoW

Source: *RIBA, 2021*

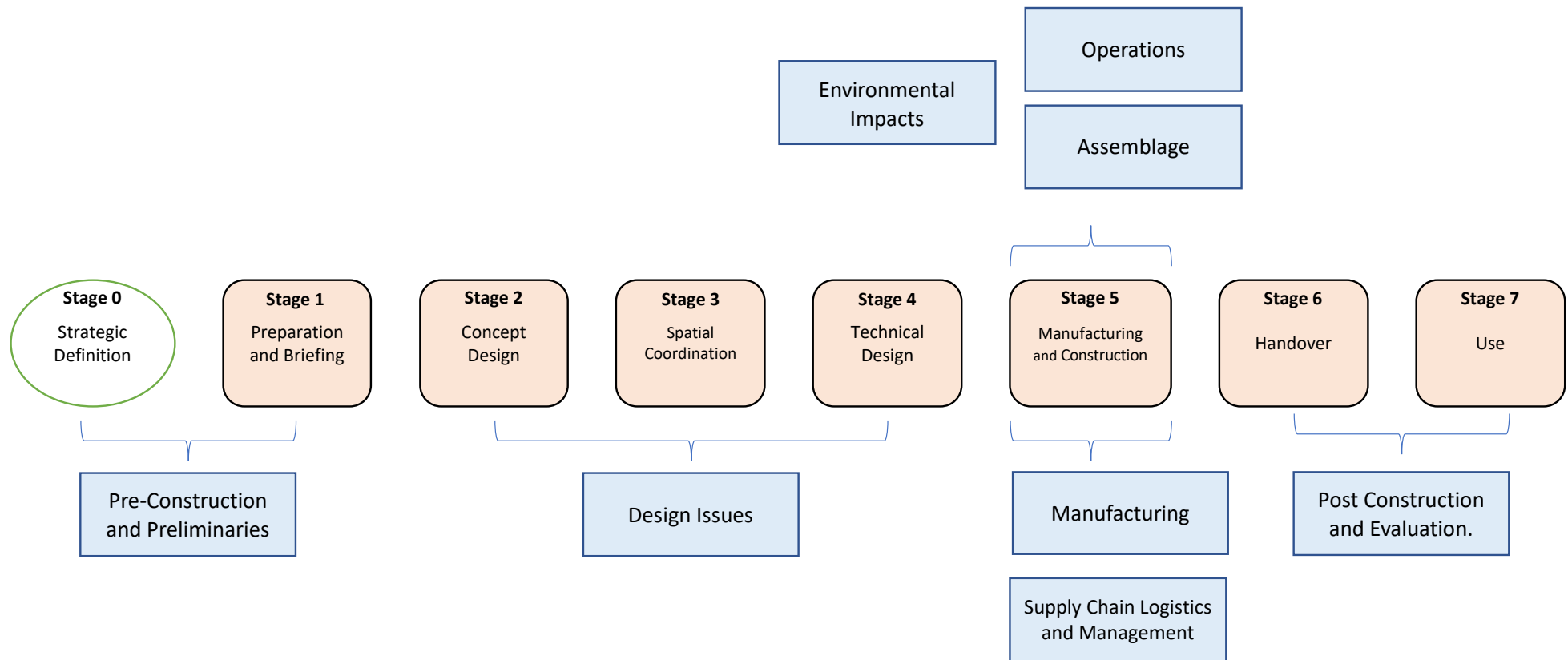


Figure 2.3.2: RIBA-PoW Stages overlaid with OSC Stages Works

Source: Author's own work , Inspired by (RIBA, 2021)

2.5.1 Review Protocol

Reviewing the stages of RIBA-PoW for OSC adoption provides insights into what areas have been covered in OSC adoption pursuit and what areas require more attention. To therefore ensure a thorough review in identifying the most researched stages of the RIBA Plan of Work (RIBA-PoW) in the context of Offsite Construction (OSC) adoption in the UK, relevant UK-focused OSC articles were sourced from multiple, reputable databases, including Elsevier's Scopus, Google Scholar, Engineering Village, Web of Science, and IEEE (*See database constraints discussed in section 2.3.1 of SLR 1*). Most articles appeared across multiple databases but given that Scopus yielded the largest collection of relevant articles, it became the primary source for this review. This approach is validated by previous research in construction-related studies (Alaka, et al., 2017; Alaka, et al., 2018, 2018; Chen et al., 2010; Malla et al., 2021; Saad, et al., 2023; Wuni, 2022; Wuni & Shen, 2022), where Scopus served as the main literature database due to its robust indexing and user-friendly features, especially in applying inclusion and exclusion criteria (Alaka, et al., 2018).

Over 90% of the articles reviewed were peer-reviewed journal publications and conference papers, reflecting a high level of scholarly scrutiny. During a preliminary search, it was noted that the term "Offsite Construction" (OSC) was used in various ways by different authors to describe non-traditional construction methods (Taylor, 2010; Wusu et al., 2022). Related terminologies, such as Modular Integrated Design (MiC), Precast Construction (PC), Prefabricated Buildings (PB), Industrialized Building Systems (IBS), and Pre-manufactured Pre-finished Volumetric Construction (PPVC) were also identified (Lou et al., 2022; McAllister, 2015).

The search keywords were framed as: ("offsite" OR "MMC" OR "Modern Methods of Construction" OR "Industrialised Building System" OR "Portacabins" AND "construct*" AND "adopt*") AND (LIMIT-TO (AFFILCOUNTRY, "United Kingdom")). The search was restricted to the years 2000-2024, in line with Wuni and Shen (2021) who noted that majority of research works on OSC occurred within the last two decades. The initial search returned eighty-five articles. The final eligibility criteria required that the selected articles focus on the UK, discuss OSC in one form or another, and address a phase of the RIBA Plan of Work or its Design for Manufacture and Assembly (DfMA) overlay. Excluding articles that fall outside the eligibility criteria, including one article in the medical field, eighty-four articles are left for further analysis. These were exported to Excel for examination based on the study's Phenomenon of Interest (POI), as noted above.

The review findings, presented by **Figures 2.3.3a-b**, highlights the yearly distribution of published articles and a descriptive statistical analysis of the reviewed articles and the categories of literature reviewed. **Figure 2.3.3a**, indicates that the majority of UK-focused OSC research in the last two decades has been conducted in the past seven years while **Figure 2.3.3b** shows that majority of the reviewed literature are articles.

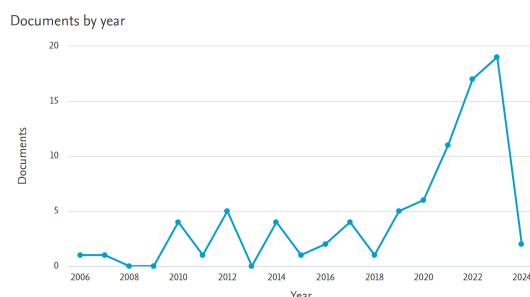


Figure 2.3.3a: SLR Documents by publication year
Source: Scopus database analysis

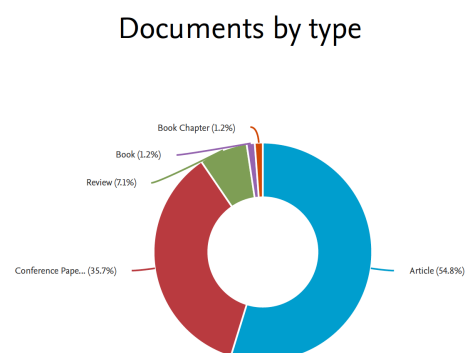


Figure 2.3.3b: SLR Documents by subject area
Source: Scopus database analysis

2.5.2 Data sorting, cleaning and review outcomes

A scoping review was done to set the tone for the SLR. The abstract of the eighty-four (84) retrieved articles were read three (3) times. A first cursory reading identified and separated the articles that focused on the UK from those that do not. This excluded thirty-eight (38) articles. The second reading focused on eliminating articles not discussing OSC in one form or the other, one article was excluded. The third reading sieved out two articles that were not particular about any stage of RIBA-PoW. A total of forty-five (45) articles were therefore evaluated for understanding OSC adoption State-of-Arts progress using RIBA-PoW. So, from the 84 articles initially considered, 45 articles that satisfied the review's POI were reviewed. The SLR process flow chart is given in *Figure 2.3.4. See Table 2.4* for articles selected.

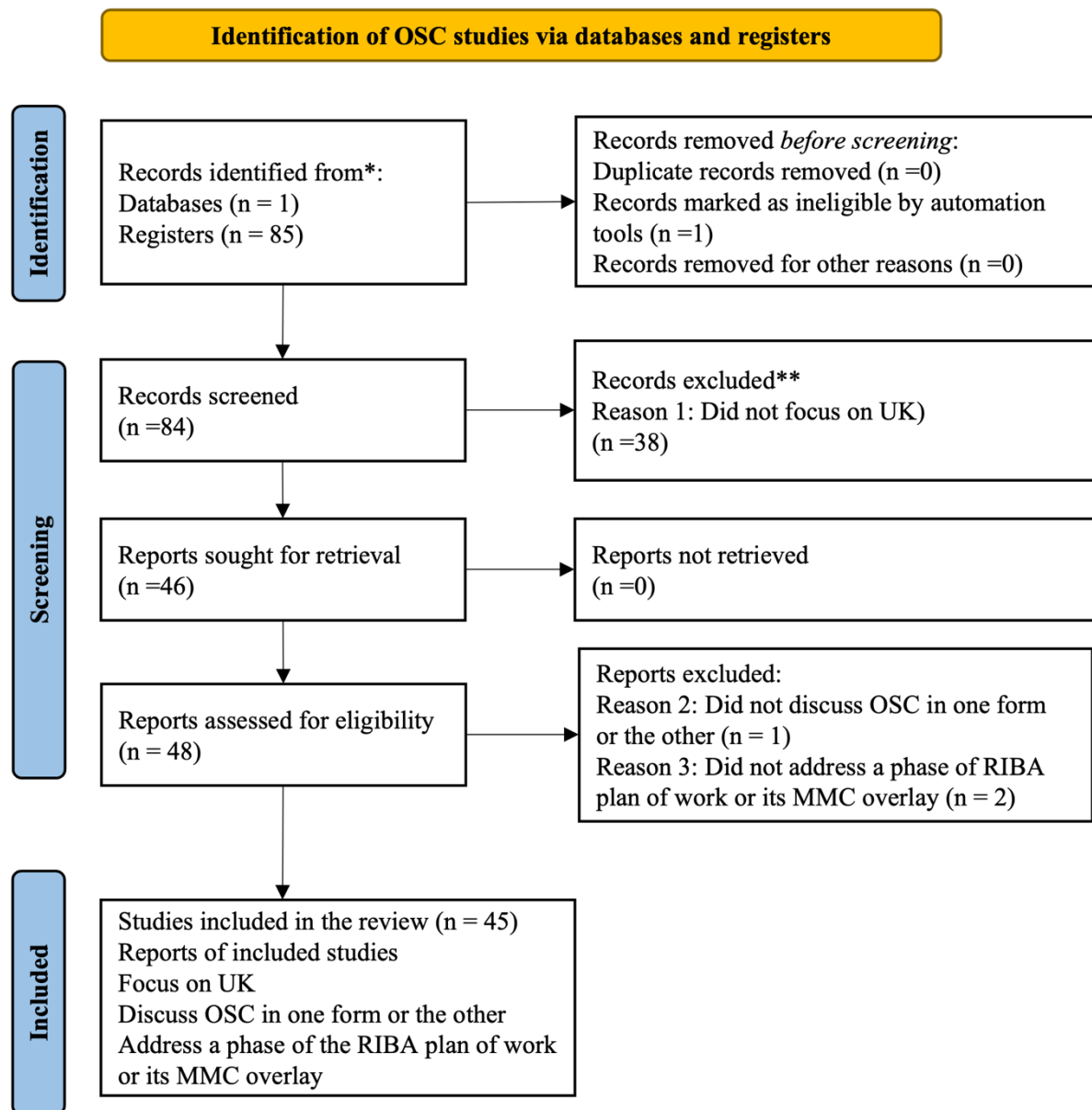


Figure 2.3.4: Systematic Literature Review Process Flow Chart

Table 2.4: Findings from SLR 3

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related SLR Decision Factor/ Themes
1	Dowsett R.M.; Green M.S.; Harty C.F. Speculation beyond technology: building scenarios through storytelling.	2022	UK focused	Design and architectural fabrication, construction, business model, supply chain, impact of construction SMEs on organizations and contractual relationships.	Stages 0-5	Construction business and cost management. Supply Chain Mgt.
2	Charlson J.; Dimka N. Design, manufacture and construct procurement model for volumetric offsite manufacturing in the UK housing sector.	2021	UK focused	Procurement routes and forms of contract, manufacturing approaches in construction	Stage 5	Construction business and cost management. Supply Chain Mgt.
3	Sanna F.; Hairstans R.; Leitch K.; Crawford D.; Menendez J.; Turnbull D. Structural optimisation of timber offsite modern methods of construction	2012	UK focused	Construction Market, manufacturing	Stage 5, 7	Construction business and cost management.
4	Agapiou A. Barriers to Offsite Construction Adoption: A Quantitative Study among Housing Associations in England	2022	UK focused	End-users' perception and evaluation of OSC project delivery,	Stages 6 & 7	User's Perception of OSC
5	Ofori-Kuragu J.K.; Osei-Kyei R.; Wanigarathna N. Offsite Construction Methods—What We Learned from the UK Housing Sector	2022	UK focused	Quality assurance in pre-construction and manufacturing	Stages 0 & 5	Improved Productivity

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related Decision Factor/ Themes	SLR
6	Saad A.M.; Dulaimi M.; Gorse C. Prospects of Promoting MMC across the Public Construction Sector: A Systematic Review against the Diffusion of Innovation Theory	2023	Assumed to be UK focused based on the premise of 'public sector'	Low Public sector adoption. Supply and demand, decision-making, and supply's business models, manufacturing	Stages 0, 1, 5 & 7	Supply Chain Mgt.	
7	Saad A.M.; Zulu S.L.; Dulaimi M. “It's your fault!” – said a public client to modernity advocates: an exploration of UK public sector's viewpoints on the modern methods of construction.	2023	UK focused	Lack of understanding of the influence of public clients' perceptions on their adoption's indecision.	Stage 7	User's Perception of OSC	
8	Abdullah M.R.; Egbu C. Selection criteria framework for choosing industrialized building systems for housing projects.	2010	Focused on Malaysian housing sector focus, it compared factor influencing decisions in the UK as well.	A structured and holistic approach in decision-making for selecting the type of IBS is important and needed in housing projects	Stages 0 & 1	Decision Support System, Construction Industry Management	
9	Ayinla K.; Cheung F.; Skitmore M. Process Waste Analysis for Offsite Production Methods for House Construction: A Case Study of Factory Wall Panel Production	2022	Assumed focus on UK based on authors affiliation	OSM production methods that replicate site arrangements and activities involving significant manual tasks do not necessarily provide a marked improvement over the conventional onsite method, manufacturing	Stages 1-5, majorly 5	Productivity, Supply Chain Mgt.	

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related Decision Factor/ Themes
			and project used.			
10	Oti-Sarpong K.; Burgess G. Offsite manufacturing and construction industry transformation: A multi-level sociotechnical transitions perspective	2020	UK focused	Conceptualise how an industry-wide uptake of OSM rests on the creation of a dominant platform around which other innovations will coalesce, to 'break through' and trigger changes in the existing configurations defining the way the construction industry works, manufacturing	Stage 5	Communications Platforms, Supply Chain Mgt.
11	Ashayeri I.; Goulding J.; Heesom D.; Arif M.; Moore N.; Obi L.; Ahmed N.; Saini M. Implementation of a novel data-driven approach to optimise UK offsite housing delivery.	2022	UK focused	Paucity of knowledge and data	Did not discuss RIBA PoW stages but noted deficiency in Stages 6 & 7	OSC Knowledge, Communications and Data Management
12	Ayinla K.; Vakaj E.; Cheung F.; Tawil A.-R.H. A semantic offsite construction digital Twin-Offsite Manufacturing Production Workflow (OPW) ontology	2021	Assumed focus on UK based on authors affiliation and project used.	Paucity of knowledge and data	Relatable to Stage 0	OSC Knowledge, Communications and Data Management

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related Decision Factor/ Themes	SLR
13	Rahman M.M. Barriers of implementing modern methods of construction	2014	UK and China compared	This study examined the importance of various barriers, such as cost, client and MMC experience to wider adoption of MMCs.	Relatable to Stage 0	Decision Support System, Construction Industry Management	
14	Saad A.M.; Dulaimi M.; Zulu S.L. A Systematic Review of the Business Contingencies Influencing Broader Adoption: Modern Methods of Construction (MMC)	2023	UK Focused	OSC adoption among public construction sector, the challenge of existing business models responsible for driving broader OSC demand, supply business models to communicate confidence, MMC firms embracing specific reforms when communicating confidence to public clients	Stages 0 & 1	Decision Support System, Construction Industry Management, Supply Chain Mgt.	
15	Kechidi S.; Banks N. Minimising upfront carbon emissions of steel-framed modular housing: A case study	2023	Focused on UK	Carbon emissions of steel-framed modular housing, sustainability, supply chain and replacement materials decarbonisation projections, manufacturing	Stage 5	Carbon Emission, Environmental Sustainability	
16	Tennant S.; McCarney M.; Tong M.K.L. Re-engineering the construction supply chain: Transferring on-site activity, offsite.	2012	Focused on UK	Supply chain management, manufacturing	Stage 5	Supply Chain Management	
17	Obi L.; Arif M.; Daniel E.I.; Oladinrin O.T.; Goulding J.S.	2023	Assumed focus on UK based on	Circular economy, manufacturing	Relatable to Stage 0 & 5	Sustainability, Supply Chain Management	

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related Decision Factor/ Themes
	Establishing underpinning concepts for integrating circular economy and offsite construction: a bibliometric review		authors affiliation and project used.			
18	Pavlović A.; Rust G.; Edwards H. Decarbonising Precast Concrete Manufacturing: Implementation of Low-Carbon Concretes	2023	UK focused	Sustainability research involving carbon emission reduction in precast concrete production, manufacturing	Stage 5	Sustainability, Supply Chain Management
19	Marte Gómez J.A.; Daniel E.I.; Fang Y.; Oloke D.; Gyoh L. Implementation Of Bim and Lean Construction in Offsite Housing Construction: Evidence from the UK	2021	Focused on UK	Assessing the current situation of the implementation of BIM and Lean Construction in OffSite Housing Construction in the UK. Sustainability using Lean Construction, manufacturing	Stage 5	Communications and Data management, Environmental Sustainability, Supply Chain Mgt.
20	Boothman C.; Higham A.; Scott A. Delivering school buildings using off-site construction: Stakeholders perceptions	2014	Focused on UK	End-users (school) evaluation Professional team evaluation of the school project	Stages 6 & 7	User's Perception of OSC
21	Lang R.; Goodier C.; Glass J. Are housebuilders' production strategies a barrier to offsite construction uptake in the UK?	2016	Focused on the UK and probable end-users	Raising housing production output Reducing house inflation Production strategies employed by private house building firms Housebuilding industry, OSC manufacturers and construction research UK's housing supply, construction	Stages 5, 6 & 7	User's Perception of OSC Productivity, Supply Chain Mgt.

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related SLR Decision Factor/ Themes
22	Vernikos V.K.; Goodier C.I.; Gibb A.G.F.; Robery P.C.; Broyd T.W. Offsite innovation in UK infrastructure: The role of the approvals process in box jacking projects.	2011	Focus on the UK	Understanding the ways that organisations influence the sector's confidence regarding innovative construction methods and materials could help accelerate their development in the design and construction process, and hence also help maximise the possibilities of modernisation in the sector	Stages 6 & 7	Planning Authorities, Quality Improvement, Supply Chain Mgt.
23	Sutrisna M.; Goulding J. Managing information flow and design processes to reduce design risks in offsite construction projects.	2019	Considered the UK and Australia	Contextual drivers and market maturity quality of information flow, in particular, the impact and influence of this on design risks in offsite construction projects design, offsite (manufacturing), handling and transporting, site works and installation and occupancy	Stages 2, 3 & 4; Relatable 5 and providing information on 6 & 7	Information Management, Communications and Data Management
24	Young B.E.; Seidu R.D.; Thayaparan M.; Appiah-Kubi J. Modular construction innovation in the UK: The case of residential buildings	2020	Focused on UK	Increasing demand for housing and wider concerns over the need to improve performance. The level of satisfaction with the modular construction	Stages 6 & 7	User's Perception of OSC, Productivity
25	Martin H.; Garner M.; Manewa A.; Chadee A. Validating the Relative Importance of Technology Diffusion Barriers—Exploring Modular Construction Design-Build Practices in the UK	2024	Focused on UK	Research on adoption factors, not really focusing on any RIBA stage.	Relatable to Stage 0	Decision Support System, Construction Industry Management,

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related Decision Factor/ Themes	SLR
26	Saad A.M.; Dulaimi M.; Arogundade S.; Zulu S.L.; Gorse C. Modern methods of construction (MMC) and innovation negativism in the UK public sector	2024	Focused on UK	Economy of scale Driving key clients to accept the MMC Public clients' indecision towards broader MMC	Stages 6 & 7	Decision Support System, Construction Industry Management	
27	Oti-Sarpong K.; Pärn E.A.; Burgess G.; Zaki M. Transforming the construction sector: an institutional complexity perspective	2022	Focused on UK	Institutional implications of transformation agenda.	Stage 5 & 7	Innovative Disruption, Design and Construction Technology	
28	Oti-Sarpong K.; Shojaei R.S.; Dakhli Z.; Burgess G.; Zaki M. How countries achieve greater use of offsite manufacturing to build new housing: Identifying typologies through institutional theory	2022	Assumed focus on UK based on authors affiliation and project used.	Applying institutional theory to analyse the factors driving greater use of OSM to build new housing	Stage 7	User's Perception of OSC, Productivity	
29	Ozorhon B.; Abbott C.; Aouad G. Integration and leadership as enablers of innovation in construction: Case study	2014	Focused on UK	Investigating the components of the innovation process by placing particular emphasis on the enablers of, as well as barriers to, innovation adoption. Interorganizational factor roles in implementing successful innovations.	Relatable to Stage 7	Innovative Disruption, Communications and Data Management	

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related Decision Factor/ Themes	SLR
30	Looby K.H.; Smith S.T.; Shahrestani M. Attitudes towards offsite prefabrication: a fuzzy approach to examining uncertainty within U.K. industry perception.	2022	Focused on UK	Explored the uncertainties in perception for a broad range of Offsite Production applications.	Relatable to Stage 0 & 7	User's Perception of OSC	
31	Adebayo A.K.; Price A.D.F.; Gibb A.G.F. Impact of modern methods of construction on healthcare infrastructure	2006	UK focused	Regeneration of several existing hospitals and the construction of 100 new ones by 2010 Involvement of the private sector in healthcare provision	Relatable to Stage 7	User's Perception of OSC	
32	Ajayi S.; Brinklow-Harris J.; Alaka H.A.; Dauda J.A. Managing the benefits and impediments to offsite construction in the UK construction industry	2019	Focused on UK	Increasing the supply of housing and addressing productivity in the construction industry. Investigating the strategies for further harnessing the benefits of the increasingly important method of construction, construction	Relatable to Stage 5 & 7	Productivity, Supply Chain Management	
33	Saad A.M.; Dulaimi M.; Zulu S.L.; Gorse C. Are the characteristics of public clients influencing their uptake of the modern methods of construction? A thematic analysis	2023	Assumed focus is UK based on authors' affiliations	This paper utilises the diffusion of innovation (DOI) theory which offers constructs that help explain the influence of the characteristics of a decision-making unit.	Stages 6 & 7	Decision Support System, Construction Industry Management	
34	Nawi M.N.M.; Pozin M.A.A.; Kamar K.A.M.; Lee A.; Harun A.N.	2018	Focused on UK	Ill-defining the MMC-IBS terms leads to misunderstanding, uncertainty and prejudice of the IBS concept and its benefits	Stage 0	Decision Support System,	

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related SLR Decision Factor/ Themes
	The global adoption of Industrialised Building System (IBS): Lessons learned					User's Perception of OSC
35	Koronaki A.; Bukauskas A.; Jalia A.; Shah D.U.; Ramage M.H. Prefabricated engineered timber schools in the United Kingdom: Challenges and opportunities.	2021	Focused on UK	An assessment of the opportunity for prefabricated engineered timber construction methods to help meet the demand for new primary and secondary school buildings in the UK.	Stage 5, 7	Decision Support System, User's Perception of OSC
36	Gbadamosi A.-Q.; Oyedele L.; Mahamadu A.-M.; Kusimo H.; Bilal M.; Davila Delgado J.M.; Muhammed-Yakubu N. Big data for Design Options Repository: Towards a DFMA approach for offsite construction	2020	Focused location not stated	Lack of information for assessing prefabrication alternatives and the choices of suppliers Connecting BIM clients to manufacturers/supplier's information such as prefab component cost and production lead times., manufacturing	Stage 5	Information Management, Communications and Data Management, Supply Chain Management
37	Nadim W.; Goulding J.S. Offsite production in the UK: The way forward? A UK construction industry perspective	2010	Focused on UK	UK construction industry's perception of offsite production (OSP) adoption/uptake using industry organizations and professionals	Stages 7	Industry professionals' perception
38	Hairstans R. Timber offsite Modern Methods of Construction	2010	Assumed Focused on UK based on author's affiliation.	Key concepts of off-site MMC and the relative structural impacts of its adoption., construction	Stage 0, relatable to stage 5	Structural Performance, Design and construction technology

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related Decision Factor/ Themes	SLR
39	Dowsett R.; Green M.; Sexton M.; Harty C. Projecting at the project level: MMC supply chain integration roadmap for small housebuilders	2019	Focused on UK	Development and application of an alternative approach to road mapping that departs from the normative linear examples of roadmaps found within the technology-road mapping literature.	Stage 5	Decision Support System, Supply Chain Mgt.	
40	Saad A.M.; Dulaimi M.; Zulu S.L. Examining the Influence of UK Public Clients' Characteristics on Their Own Innovation-Decision towards the Modern Methods of Construction (MMC)	2023	Focused on UK	This study investigated the characteristics that are responsible for public clients' low MMC uptake despite the associated relative advantages.	Stage 7	Decision Support System, User's Perception of OSC	
41	Pan W.; Gibb A.F.; Dainty A.R.J. Perspective of UK housebuilders on the use of offsite modern methods of construction	2007	Focused on UK and probable end-users Important reference perspectives of UK house builders, as it is unclear.	Investigation of UK housebuilders' views on the use of offsite modern methods of construction (offsite MMC)	Stage 7	Decision Support System, User's Perception of OSC	
42	Archila H.F.; Lashley R.; Lamond J.; Prabhakaran A.; Msipo A.; Escamilla E.Z. 'Smartifying' Construction for Circular and Zero-Carbon Biobased Buildings (SmartBioC)	2023	Focused on UK	Using the UK's Design Council's Beyond Net Zero Framework of exploring, reframing, creating and catalysing to facilitate a collaborative and iterative process where the end-user is at the centre and determines the outcome.	Stage 5, related to stage 0 & 7	Decision Support System, User's Perception of OSC,	

S/ No	Authors/Title/Date	Date	Location Focus	Core Influencing Factor(s) Examined	Stage of RIBA PoW/MMC overlay addressed	Related SLR Decision Factor/ Themes
						Environmental Sustainability
43	Moorhouse V.; Littlewood J.R.; Hale E. A Pilot Study Evaluating Offsite Manufacturing of Timber Frame Panels Using Lean Manufacturing Principles for Dwellings	2021	Focus on UK	Evaluating the manufacturing process of an offsite manufactured (OSM) timber frame (TF) modern methods of construction (MMC) exterior wall panel, construction	Stage 5	Manufacturing, Design and construction technology
44	Maqbool R.; Bhuvaneswaran M.; Rashid Y.; Altuwaim A.; Ashfaq S. A Decision Approach for Analysing the Role of Modern Methods, Project Management and Integrated Approaches in Environmentally Sustainable Construction Projects	2023	Focused on UK	Identifying a justifiable strategy to improve sustainable construction success, construction	Stage 5	Decision Support System, Environmental Sustainability
45	Saad A.M.; Dulaimi M.; Zulu S.L. Broader use of the Modern Methods of Construction (MMC) in the UK public sector: A Business Model Canvas (BMC) perspective	2023	UK focused	MMC firms' business strategies contributing to public clients' indecision.	Stage 0, relatable to stage 7	Decision Support System, User's Perception of OSC, Construction Industry Management

2.5.3 SLR 3 Analysis and Findings

This section analysed the forty-five (45) articles for this review (*See Table 2.5*). It also discussed the final selection method and outlines the findings from the content and thematic analysis. The findings were overlaid on the RIBA plan of work (POW) to identify and understand what areas of the PoW have been sufficiently covered and areas requiring more attention. This is important for advancing OSC adoption by unearthing what areas require more efforts and attention.

Table 2.5: Analysis of the Reviewed Articles and the Stages of RIBA-PoW discussed.

S/ No	RIBA Stage(s) Discussed in Article	Number of Articles
1	Relatable to Stage 0 & 5	1
2	Did not discuss RIBA PoW stages but noted deficiency in Stages 6 & 7	1
3	Relatable to Stage 0	3
4	Relatable to Stage 0 & 7	1
5	Relatable to Stage 5 & 7	1
6	Relatable to Stage 7	2
7	Stage 0	1
8	Stage 0, relatable to stage 5	1
9	Stage 0, relatable to stage 7	1
10	Stage 5	10
11	Stage 5, 7	3
12	Stage 5, relatable to stage 0 & 7	1
13	Stage 7	4
14	Stages 0 & 1	2
15	Stages 0 and 5	1
16	Stages 0-5	1
17	Stages 0,1, 5, 7	1
18	Stages 1-5, majorly 5	1
19	Stages 2, 3, 4 relatable to Stage 5 and providing information on 6 & 7	1
20	Stages 5, 6 & 7	1
21	Stages 6 & 7	6
22	Stages 7	1
	Total	45

A breakdown of the studies show that eight (8) studies have explored issues on stage 0 of the RIBA PoW while four (4) studies also explored issues relating to stage 0, though not focused on it. Total studies that explored RIBA PoW stage 0 from the review in one form or the other was twelve (12). Four (4) studies investigated stage 1, only one (1) study looked at stage 2, 3 and 4. Nineteen (19) studies explored stage 5, while four (4) studies were related to stage 5. A total of 23 studies examined stage 5 in one form or the other. Seven (7) studies explored stage 6, and two (2) studies discussed issues relating to stage 6. A total of nine (9) studies touched on stage 6. Thirteen (13) articles explored stage 7. *See Table 2.6* for summary of findings from SLR 3.

NB: The RIBA-PoW was designed exclusively for traditional construction method and overlaying it on MMC procedure is still very subjective at this stage owing to a lot of technical, legal and administrative considerations that would go into doing so.

Table 2.6: Summary of RIBA stage of works identified by reviewed articles.

S/ No	RIBA Stage Discussed in Articles	Stage Focus	Number of Articles	Stakeholder Grouping
1	Stage 0	Strategic Definition	12	Intermediate Phase, 16 Technical Category (Intra UKCI group) 22
2	Stage 1	Preparation and Briefing	4	
3	Stage 2	Concept Design	1	
4	Stage 3	Spatial Coordination	1	
5	Stage 4	Technical Design	1	
6	Stage 5	Manufacturing and Construction	19	Non-Technical Category (Inter UKCI group) 22
7	Stage 6	Handover	9	
8	Stage 7	Use	13	

This finding suggest that the more technical phase of the RIBA-PoW have experienced wider research coverage as much as the non-technical phase. However, some areas of the technical phase, particularly the manufacturing and construction (Stage 5) have been largely researched

at the expense of the others. Similarly, Use, under the non-technical phase is also more researched than Handover. For the Use (Stage 8), studies have paid more attention to house builders and housing associations than end-users (occupants). The interphase between the technical and non-technical streams (Stages 0 and 1) have been least researched. The lower focus on end-users and the low studies on stages 0 and 1 may be suggestive of the lopsided understanding available at the take-off phase of OSC projects, resulting in low OSC adoption.

2.5.4 Discussion

This study identified the most explored stage of the RIBA-PoW to be Stage 5 which focuses on manufacturing and construction. Further scrutiny on this stage, as noted from in-depth study of the reviewed articles, shows that more articles focused on manufacturing than construction. The areas explored in manufacturing are use of lean approach, quality assurance, supply and demand via business models, marked improvements, creating dominant workable platforms for OSC uptake, sustainability, carbon emission reduction and circular economy, and production information management. Articles on construction works on OSC at stage 5 explored sustainable construction success, use of timber frame for exterior wall panel, structural impacts of OSC adoption, and OSC method of site construction.

Stage 7, Use, is the second most researched RIBA-PoW stage. Articles from this stage examined different OSC end-users/clients. The studies identified three (3) classes of end-users, namely Housing bodies (Housing Associations, House Builders, and such.), sector end-users (Civil engineering, NHS, MMC firms, Education bodies) and public clients. Issues examined by the Stage 7 articles are perceptions, social values, implications, indecision, end-user satisfaction and lack of understanding from the different end-users identified. Attention

appears to have concentrated on sector end-users than public clients, where a larger number of potential clients appears to be.

The third most explored RIBA-PoW stage with respect to OSC wider adoption from the review is stage 0-Strategic Definition. Some of the issues addressed in the studies are Business Models, design and architectural fabrication, impacts on organizations, construction SMEs (Small to Medium sized Enterprise), contractual relationships, quality assurance in pre-construction and manufacturing, supply and demand, decision making, selection criteria, cost, time and environmental impact evaluation, communicating confidence about OSC, perception, OSC context, MMC firms' business strategies, clients' indecision.

Another stage of RIBA-PoW that has been well explored from the reviewed articles is stage 6-Handover. The handover stage considers end-users concerns, understanding public clients, economy of scale, improved performance, level of satisfaction, occupancy, regulations and social aspect, evaluation of project delivered regarding sustainability, continuity with OSC in delivering more houses, planning challenges and circular economy.

The stages least explored from the extracted articles are stages 2, 3 and 4 and are all relating to design.

SLR 3 Review Summary

The most researched stage of the RIBA-PoW is Stage 5 (Manufacturing and Construction) while the under researched stages are the design phase, encompassing stages 2, 3, and 4 of RIBA-PoW. While the post construction and evaluation phase are critical to gathering feedback for improving OSC adoption strategies, the design phase is equally critical to ensuring made-

to-fit manufacturing and accurate onsite assemblage. Though post-construction evaluation related issues ranked the most researched stages of RIBA-PoW, it lacked adequate attention to end-users' feedback from project use perspective. This agrees with study of Moradibistouni et al., (2019) that the pursuit of wider OSC adoption lacks end-user's opinion/feedback in the OSC adoption scheme. On the other hand, this review confirms the UK as one of the frontiers of OSC usage on a global level, considering the volume of research on OSC manufacturing, construction, post-construction and preliminary RIBA-PoW stages. The study infers that the failure or oversight of extant studies not to relate the aim of their studies to specific phase(s) of the RIBA plan of work or the DfMA overlay may be one of the reasons for the mixed-up solutions being proffered in advancing OSC adoption.

This review is the first to use the RIBA Plan of Work to analyse OSC adoption in the UK, setting a framework for institutional appraisal. It identified key areas needing further work to drive wider adoption and offers a template for other countries to assess their OSC progress within the limits of their institutional guides. For academics, it highlights research gaps to increase OSC use, and for industry practitioners and policymakers, it provides insights on where to focus efforts and resources effectively. While the analytic template would be of endless use in ages to come, its use in this review is limited to the scope of work in this study.

A limitation to this study is that only a few articles from the database search focused on UK-OSC works solely. Being able to extract more UK-OSC articles may change the dynamics of this report.

2.6 Chapter Summary

The three SLRs conducted are both meta-analytic (in that they generate a content -quantitative- analytical breakdown of effect sizes, identifies patterns and analyse relationships) and meta-synthetic (in that they synthesise themes, concepts and interpretations in generating new theoretical insights, deepen understanding and create interpretive synthesis of qualitative findings).

The reviews submit that the **present** analytic progression of extant studies from factor to themes without an understanding of the underlying issues cumulating into the factors has created an overlap in the degree of influence of the themes which are mostly used to analyse and discuss OSC adoption. This is because some themes possess both inhibitory and driving characteristics. Commencing the evaluation of OSC adoption influencing factors from the factor constituting issues will enhance clarity and address lopsided understanding around OSC adoption which already is aggravated by users' perception following failures associated with the initial use of OSC.

The reviews also submit that there is a dearth of theoretical approaches undergirding studies on OSC adoption. Adopting OSC in place of traditional method is a change approach but most studies on OSC do not consider this in their adoption approach or analysis.

While the RIBA-PoW exists and has instructed construction procurement in the UK, an evaluation of research works on OSC adoption suggests that only some parts of the RIBA-PoW, like the manufacturing and construction stage, received good attention at the expense of the others. A particular area that appears important but under-researched is the role of end-

users in post-construction evaluation (Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025). While the study admits that the RIBA-PoW was expressly designed for conventional construction procurement and that efforts have been made to overlay it with DfMA-PoW, the study submit that, considering the factory-approach to OSC/MMC production where the bulk of the OSC works occur, the stage 5 (Manufacturing and Construction) of the RIBA-PoW needs to be revised to reflect clearer activities as relates to MMC/OSC uptake, inclusion and adoption.

Finally, this study recommends that, owing to the myriad of factors influencing OSC adoption from the review (over 600 issues accounting for over 100 factors), the multi-faceted nature of CI and the complexities associated with addressing OSC integration into the industry, aggregating and analysing project information and data from past successful and failed OSC and on-going projects is the most realistic way to understand and address low OSC adoption in the UK and globally.

CHAPTER THREE

3.0 THEORIES

Chapter Overview

This chapter explored theoretical underpinnings for adoption related studies and the unique perspectives each impacts on adoption. It identified ADKAR and CBAM as the most applicable theories to this study. Combining the complimentary strength of both, the study was able to address the dearth of theories in construction, engineering and management studies, noting the need for an all-encompassing theory that addresses social and technical dynamics for wider OSC adoption.

3.1 Theories and Adoption

Initial studies that addressed adoption of the rejuvenated OSC concept (Zhang et al., 2019b) did it primarily through presenting its benefits and challenges to the construction industry and the UK government, (e.g., (Abdelmageed et al., 2020; Ajayi et al., 2019; Blismas et al., 2005, 2006)). OSC concept however involves a lot of activities and stakeholders beyond just the government of UK and her construction industry. Indeed, the government has incentivised the industry and there is appreciable adoption of the concept within the industry. However, the government has further requested for a 25% or more use of OSC in projects (CIC, 2013; CLC, 2020) which the current OSC adoption roadmap has not met.

While earlier efforts have ensured design (conceptualisation and full scale drawing developments), manufacturing and partly supply chain logistics adoption to some level, they

have not translated to the desired amount of adoption requested (UK Parliament, 2023, 2024a). SLRs 2 and 3 unearthed the theory challenges from extant literatures on OSC adoption and the sections within the industry that have advanced with the use of OSC and the areas needing a push on OSC adoption.

Today, OSC advocacy is no longer for just adoption, but for wider adoption of OSC on all construction sections/phases and projects (Payne & Serin, 2023). Most research works on OSC are still focused on adoption instead of wider adoption. Recent studies, (e.g., Saad, et al., 2023a) however have started calling for wider or broader OSC adoption. For this to become a reality, it will require inclusion of the different construction stakeholders, beyond the government and industry. For instance, the construction sector involves design conceptualisation, manufacturing, construction (on-site assemblage), marketing, energy use, user comfortability, human resource management. To therefore understand how OSC can become a product demanded by most stakeholders (Zhang et al., 2019b), it requires the application of relevant theories that can help achieve this (Ehwi et al., 2022).

The construction Industry appears to be of two major streams of stakeholders- those within the construction industry (intra) and those outside the construction industry (inter). What is however observed from the reviews is that extant studies do not factor in the inter and intra related allied activities of the construction industry in the pursuit of wider OSC adoption. The outcome of this, with respect to adoption pursuit and according to the reviews, is that the ‘intra’ and ‘inter’ streams appear to have received similar research attention. However, the interphase between both, which is the Strategic Definition (Stage 0), and the Preparation and Briefing

(Stage 1) observed a lower research attention, suggesting a slight disconnect between the technically inclined intra stream and the socially inclined intra stream. *See SLR 3*

Additionally, the adoption of Offsite Construction (OSC) technologies within the traditionally conservative construction industry is not merely a technical or operational decision, where most adoption efforts have been concerted in the past. It is fundamentally a change management challenge. Moving stakeholders from long-entrenched site-based methods to factory-based, process-driven production systems requires a paradigmatic shift in organisational behaviour, individual readiness, institutional support, and cultural acceptance. This transformation necessitates the application of well-established adoption and change management theories.

3.2 Adoption Theories in OSC-Related Studies

To commence on the study's theoretical underpinning, there is limited use of theories in construction, engineering and management (CEM) articles, inadequate application of research theories in OSC research and limited number of theoretical contribution in construction research (Ehwi et al., 2022) [CrossRef: Schweber (2015); Betts & Lansley (1993)]. This may have been influenced by the technical orientation of the current adoption pursuit, as the present plethora of articles have largely focused on 'what works' over 'why it works'-leading to minimal engagement with theoretical models. Also, the interdisciplinary nature of OSC-spanning across multiple fields may have made it difficult to apply a unifying theory.

Few studies from the reviews, (e.g., Goh & Goh, 2019; Sutrisna et al., 2018; Sutrisna & Goulding, 2019; Zhai et al., 2018, 2019) that have applied study theories are narrow in scope (using the likes of lean theory, game theory, modularisation theory, theory oriented process,

theoretical estimation and theoretical baseline among others), addressing mostly supply chain, manufacturing and on-site assemblage. A few other studies like [Zhang et al., \(2024\)](#) and [\(Jiang et al., 2017; Razkenari et al., 2020\)](#) have used change management related models like PESTEL and SWOT respectively to appraise wider OSC pursuit. Sadly, these studies are not UK-focused. Studies like [Martin et al., \(2025\)](#) and [Saad et al., \(2023\)](#)-using Innovation Diffusion Theory (IDT) and [Oti-Sarpong et al., \(2021, 2022\)](#)-using institutional theories, appraising wider OSC adoption and are UK-focused still have their studies aimed at the industry professionals and construction techniques and not the other industry stakeholders.

However, to understand the underlying mechanisms of adoption, systemise factors and provide scaffold for their relationships, enhance transferability and generalisability, facilitate predictive modelling and policy design, especially now that the question has moved from what works to why is there still low adoption despite every mechanism put in place, there is need for theory application-an encompassing on- in OSC adoption studies. For instance, if earlier studies have been informed by encompassing theories like CBAM or ADKAR, policy makers may have identified earlier that the industry is stuck in at ‘awareness’ or ‘desire’ stage and at ‘design’ or ‘manufacturing’ stage, prompting more resource investment in phases like communications, successful projects demonstration and wide skill development before mandating MMC procurement or setting ambitious increased MMC usage on projects.

The adoption theories that would drive wider OSC adoption will have to go beyond construction techniques, industry professionals and their works, and these theories appears not to have been well applied within CEM. The modern method of construction technologies introduced into the industry have rightly focused on CI-workers (tradesmen and professionals)

with little or no consideration for other stakeholders, particularly, end-users. This is understood from the fact that CI workers are the first point of call, needing to embrace the idea and employ it in production. However, these professionals only make up a negligible number of adopters (Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025). The other stakeholders make up an integral number of adopters and not capturing them in the adoption pursuit chain maximally could be responsible for the low-level OSC adoption being experienced.

While the managerial and non-managerial CI members demonstrate some level of construction knowledge and embrace OSC introduction aptly, the general UK populace, who constitute majority of OSC ‘product’ end-users, do not possess adequate knowledge of OSC (Agapiou, 2022; Nadim & Goulding, 2010; Zhang et al., 2024) nor rich awareness on what OSC entails (Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025). Moreso, the historical experience of prefab buildings still make them demonstrate some degree of restraint, evidence in the conservatism and protectionism highlighted in the review chapters (Agapiou, 2021; Looby et al., 2022; Wusu, Alaka, Oseghale, Balogun, et al., 2025; Young et al., 2020). Therefore, the theories that should be considered by scholars researching OSC adoption should be those that incorporate potential adopters outside the CI. Hence this study looked beyond the adoption models reported in extant literatures to applying models that can capture non-CI workers/professionals. While extant studies’ model like PESTLE and SWOT explored internal and external factors, most failed to address non-construction people/adopters’ concerns.

This theory application gap therefore compels this study to explore other applicable adoption theories for wider OSC adoption. To achieve this, the study considered holistic-team-focused theories and models that include change models in addition to adoption models and theories as

suggested by Zhang et al., (2024). The theories considered are highlighted below and underscores some points in the discussion phase of this study.

3.3 Adoption Theories

OSC has been described as a disruptive and innovative technology within the construction industry (Saad et al., 2021a; Yang et al., 2019), given that OSC is modern construction approach in a technology resistant field. Its re-introduction has employed some adoption guides. The theoretical frameworks considered in this study draws from existing theories that have been used to advance adoption in the field of technology innovation. Many of these technology adoption theories have been used extensively for IT/Computer adoption. Some of such theories are Roger's Innovation Diffusion Theory (IDT), The United, Theory of Acceptance of Use of Technology (UTAUT), (Munir, 2003; Ragozzino, 2006). Some have also been applied to construction industry, e.g., Technology Adoption Models (TAM), The Concerns-Based Adoption Theory (C-BAM)), Awareness, Desire, Knowledge, Ability and Reinforcement (ADKAR) Model among others (Momani et al., 2017; Shang et al., 2020; Taherdoost, 2018; Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025). Individually, these theories have their shortcomings, which do not make them particularly suitable for construction-related research in their stand-alone form (Ajibade, 2018; Momani et al., 2017).

3.3.1 Innovation Diffusion Theory (IDT)

Rogers' Innovation Diffusion Theory (1962, 2003) is a seminal framework explaining how, why, and at what rate new ideas and technologies spread. The theory is one of the earliest adoption theories and covers general adoption views like relative advantage, compatibility, complexity, trialability, and observability. These sociological views make IDT applicable to

sector-wide OSC adoption possibilities. For instance, relative advantage supports OSC's faster delivery, better quality, and reduced environmental impact characteristics, while compatibility is relevant to OSC's integration of site-based practices and procurement structures. The trialability of OSC remains limited due to the complexities involved in turning a factory design approach and production into onsite assemblage. This makes observability, i.e., visible success stories of OSC in the UK not widely known. The knowledge of this success stories are very crucial to wider OSC adoption (Morby, 2023; Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025), hence, one of the reasons IDT was not considered a good fit for this study.

Despite IDT's wide applicability, it's usage is limited by its assumed overly linear structure applicability as that do not cater for complex, iterative and real world application, aside its diminished exploratory power in delayed adoption, providing feedbacks and institutional resistance (Greenhalgh et al., 2004). Additionally, (Momani et al., 2017, page 9) noted that IDT, "*... doesn't indicate how the attitude impacts on accepting or rejecting the decisions, or how innovation factors affect on decisions. It doesn't give any concern to individual's resources or social support...*" In addition to IDT's limitations noted above, the issue of 'concern to individuals' plays a critical role in not considering IDT for this study because 'individuals' determine adoption success, among other factors (de Jonge et al., 2007; Hoyer et al., 2010; Kelley & Sánchez, 2005).

3.3.2 Technology Adoption Models (TAM)

Technology Adoption Models (TAM), like the one proposed by Davis, (1989), concentrated on limited adoption issues which are users' perceptions and attitudes toward adopting technology (Momani et al., 2017). The strength of TAM lies in its parsimonious structure and

wide empirical application in explaining early-stage technology adoption across various sectors, including health, education, e-commerce, and construction technology. Its generalisability and ease of operationalisation have made it one of the most cited and applied models in information systems and adoption research (King & He, 2006). TAM's limitation, however, lies in its individualist and technocentric assumptions, often neglecting organisational and contextual factors that are critical in complex change scenarios like OSC (Venkatesh & Davis, 2000).

Though some extensions of TAM further assessed factors such as perceived ease of use and perceived usefulness in predicting technology adoption (Lee et al., 2003), it still *"...doesn't provide any feedback on some factors that may enhance adoption like integration, flexibility, completeness of information, and information currency and it cannot predict the user's behaviour within culture"* (Momani et al., 2017). 'Completeness of information' and 'information currency' are some of the influencing OSC factors highlighted under communications as requirement that can drive OSC wider usage (Gautier et al., 2008; Razkenari et al., 2020; Sutrisna & Goulding, 2019a; Zhang et al., 2021). These limitations of TAM within the engineering domain as noted by Momani et al., (2017) make TAM unfit as a theoretical underpinning for this study.

3.3.3 The United Theory of Acceptance of Use of Technology (UTAUT)

UTAUT, developed by (Venkatesh et al., 2003) built on eight (8) adoption models, including IDT and TAM, and had strengthened the limitations of those models with four (4) constructs namely performance expectancy, effort expectancy, social influence, and facilitating

conditions. Its use is relevant to large organisations and can cater for institutional mandates, inter-organisational dynamics and stakeholder collaborations.

However, studies (Alshammari & Rosli, 2020; Williams et al., 2011, 2015) showed that UTAUT demonstrated low exploratory power in its build up to addressing business intelligence, and it does not exhibit reliable outcome across different geographical locations. Also, it exhibits low capacity in unravelling the complex relationship among its constructs. Additionally, it is data-intensive and complex in execution, making its application quite difficult in a heavily fragmented construction industry. Moreso, UTAUT lacks variability readiness among OSC stakeholders, does not address adopters concerns nor return user feedback.

Owing to its inability to address the adoption concerns and users feedback, it was not considered very suitable for this study.

3.3.4 The Concerns-Based Adoption Model (C-BAM)

The Concerns-Based Adoption Model is an adoption theory that offers a change-centred approach, focussing on individual's concerns and perceptions as it relates to adopting a new innovation or technology (Hord et al., 2006). Its framework sets out to understand and facilitate change within an adoption target group (ASCN, 2021; Garrison, 2023). It was originally developed for and has been extensively used within the education sector, identifying different stages of adopters' concern, from awareness to the innovation's effectiveness, as they adopt an innovation (Khoboli & O'toole, 2011; SEDL & AIR, 2015).

While TAM (Cai et al., 2022; Lee et al., 2003; Malatji et al., 2020) and UTAUT (Barrane et al., 2018; Li, 2020; Williams et al., 2015) have over time shown broader coverage of adoption-

related issues in various technology adoption areas and is well used in construction research works, C-BAM has demonstrated more individual feedback and user concerns in addressing wider adoption (Hord, et al., 2013; Khoboli & O'toole, 2011).

C-BAM's theoretical framework allows for a nuanced exploration of the adoption and change process beyond just the ease of use and perceived usefulness TAM2 provides (Wusu et al., 2022) and addresses the relationship among team members, a shortcoming UTAUT does not address.

C-BAM also provides a more comprehensive framework for understanding the adoption of innovations through its pillars of establishment which are creating awareness to the unconcerned, information on issues of adoption, personal strategies execution, management of adoption demands, consequences to other matters, collaboration with other stakeholders, to refocusing the entire process in order to make it work better (Hord, et al., 2013; SEDL & AIR, 2015). Though initially developed in educational settings where it found a wide range of applicability, the ordered approach of the model creates room for it to be considered by other sectors of economy and development (Garry Davis, 2015). C-BAM focuses on aspects like Innovation Configuration, Stages of Concern, and Level of Use (Chanda & Bardhan, 2008). It caters for the concerns emanating from low adoption and potential adopters' reasons for low adoption. Specifically, C-BAM addresses the following innovation and adoption issues:

- 1. Provision of innovation configuration which helps create a structured roadmap for team members, ensuring high-quality execution of goals.*
- 2. The stages of concern that enable team leads to gauge the mindset of members regarding the newly introduced innovation, thus facilitating necessary adjustments.*

3. *The level of Use that helps identify how team members are adapting to the innovation and resolving challenges, ranging from non-usage to advanced usage.*

The tripod foundational stands of C-BAM invoke its applicability on this study by ensuring all relevant stakeholders in the drive for wider OSC adoption are considered and carried along in the adoption build-up as we cannot be aiming at wider adoption by focusing on the narrow technical and construction section of the industry alone (Payne & Serin, 2023). Also, it ensures an evaluation of different members of OSC stakeholders in line with the overall OSC adoption mission statement and goal, their mindset on OSC spread and provision of relevant balance, way-forward and push needed to achieve OSC wider adoption (Saad, et al., 2023a). It further lends its relevance to this study in that it provides feedback on how the mission statement and goal is fairing against the efforts put in based on how well or how much of OSC is considered or used in construction project proposals and execution. *See Figure 3.1*

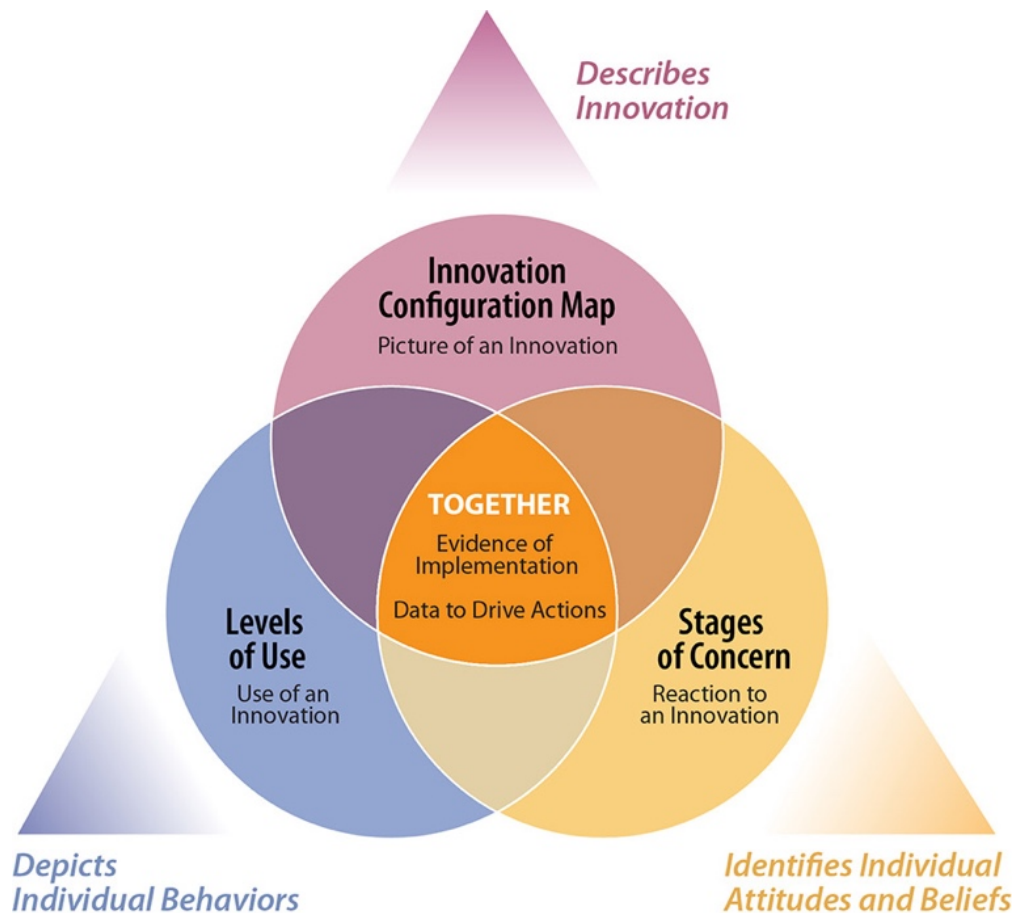


Figure 3.1: Concern Based Adoption Theory

Source: <https://sedl.org/cbam/> (2015)

The C-BAM stages span from awareness to the concerned, information, personal stage, management and implementation, consequence, and collaboration to refocusing (Khoboli & O'toole, 2011). C-BAM is particularly suitable for studying the adoption of Offsite Construction (OSC) due to its holistic approach, incorporating feedback from adopters, reactions to innovations and facilitating follow-up actions (Wusu et al., 2022). Together, these stages of concern provide an evidential approach through data-driven actions. This aligns well with the research focus on improved innovation, awareness, attitude, adoption, acceptance, usefulness, ease of use, and diffusion of use regarding OSC. In the case of this study, C-BAM

identified the area of OSC adoption concern, thereby shedding light on strategies that could possibly help in increasing adoption, as would be seen from the interview outcome (*See Chapter 5*).

However, CBAM is not without its shortcomings. While CBAM offers invaluable insight into how and why individuals adopt or resist innovations, it does not address issues like scaling to complex, multi-stakeholder environments like the construction industry. Its individual-focused lens and weakness in structural emphasis requires that it should be complimented with frameworks that have broader coverage and can make up for its weakness. Therefore, ADKAR, an organisational focused framework, was considered as a suitable compliment to CBAM.

3.3.5 Awareness, Desire, Knowledge, Ability and Reinforcement (ADKAR) Model

ADKAR stands for Awareness, Desire, Knowledge, Ability and Reinforcement. It announces the change process, thus creating a desire for the change, educating users on the reason for the change and providing room for questions and clarity on the need for the change (Creasey, 2020; Hiatt, 2006). Beyond providing a change process approach, ADKAR is a goal-oriented change management model allowing stakeholders to focus their activities on specific business needs, results and solutions, not just change processes or requirements.

ADKAR is a change management model, used for adoption related challenges by organisations (Garrison, 2023). It reinforces transitioning possibilities by considering the change process in complex systems. It is action oriented, business-rooted and scalable (Hiatt, 2006). Also, ADKAR explores the gap between both internal and external influencing factors in a system or organization. ADKAR treats distinct stages of adoption, addressing the intertwine between personal and organisation desires, thus addressing cultural and behavioural inertia and

providing interventional roadmaps on what actions to take based on what stage a stakeholder is and how to move them forward. Since the study involves transiting from one form of use to another within a multi-disciplinary sector, ADKAR was found very suitable for this study and complimentary to the individual-focused C-BAM.

However, the limitation of ADKAR is that it approaches adoption challenges in a linear progression without the option of returning to evaluate how much impact the previous stage has made or how that stage can impact the approach of the next, unlike C-BAM that appraises the concerns of adopters and level of use. This ADKAR limitation is addressed in this study by extending ADKAR model to $ADKAR \rightleftharpoons A$; a situation where awareness is used to reinforce and promote wider OSC adoption in a reversible interaction as argued by Wusu, et al., (2025). ***Refer to Section 10.1.1 and Figure 10.1.2.***

Figure 3.2 below expanded on the framework of ADKAR model.

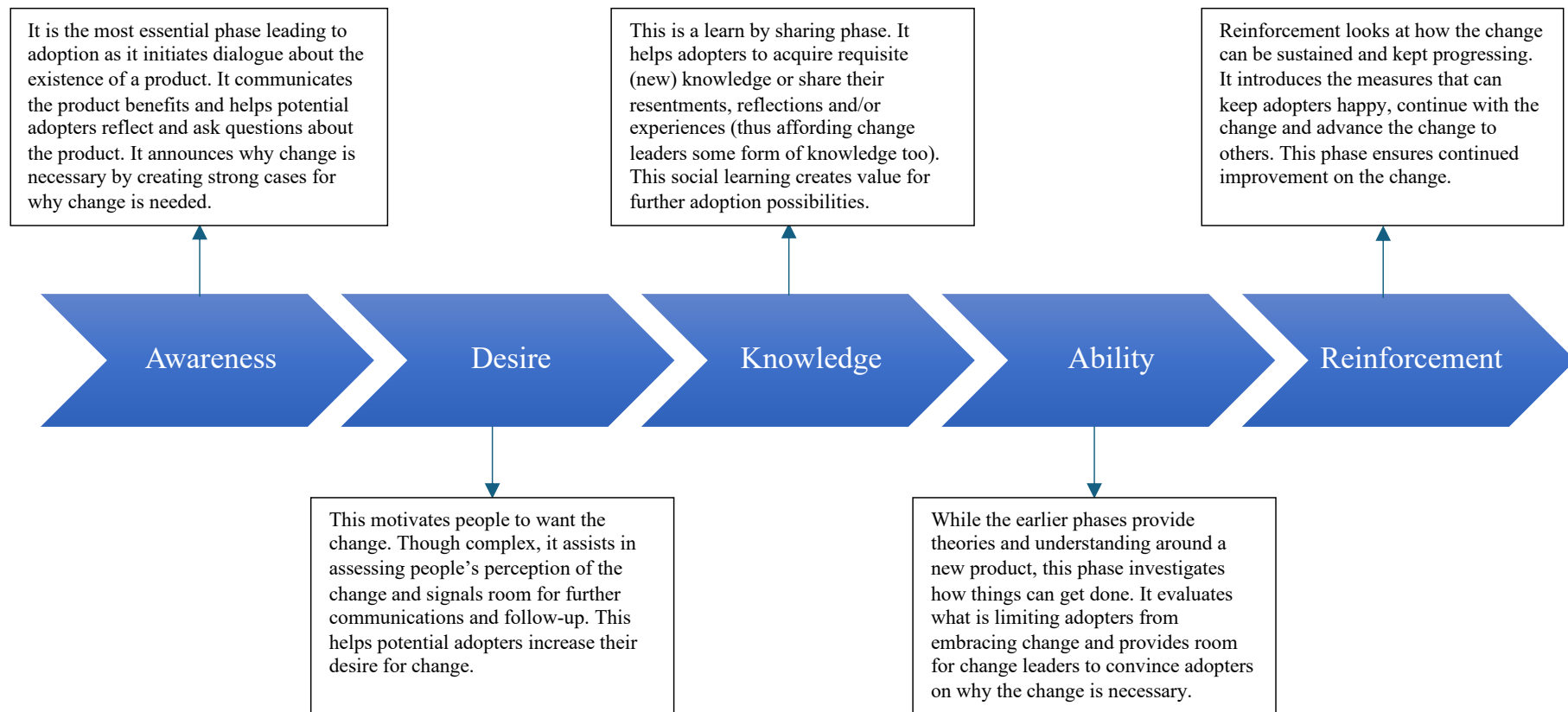


Figure 3.2: ADKAR Change Model

Source: Authors' own work (Wusu, 2025), inspired by (Prosci, 2020)

3.4 Combining C-BAM and ADKAR

From the highlighted theories above, the two most applicable to this study are C-BAM and ADKAR. While C-BAM provides a robust cyclic framework to investigate why OSC has not been widely adopted as a viable construction method by addressing issues related to innovation adoption, adoption concerns, and strategies for managing, executing and refocusing OSC adoption (Lai, 2017; Sepasgozar & Bernold, 2018; Straub, 2009), ADKAR compliments C-BAM by exploring adoption gaps or challenges at each stage of the process in a linear form.

Though C-BAM provides limited insight on how to drive the change process required for OSC wider adoption, this weakness is compensated for in ADKAR change management model. Specifically, ADKAR model provides insight on the change process, thus creating a desire for the change, educating users on the reason for the change and providing room for questions and clarity on the need for the change (Hiatt, 2006; Prosci, 2020). By so doing, the model facilitates change by using awareness to drive desire and human capital development. Complementarily, C-BAM provides a robust framework to investigate why OSC has not been widely adopted as a viable construction method, addressing issues related to innovation adoption, adoption concerns, and strategies for managing, executing and refocusing OSC adoption (Lai, 2017; Sepasgozar & Bernold, 2018; Straub, 2009) and emotions (SMC, 2009) while ADKAR addresses how much adoption can be encouraged and how reinforcing adoption achieved can further improve awareness (Wusu, et al., 2025).

Additionally, while ADKAR measures the linear adoption goal progression of stages in an organization, C-BAM focuses on assessing and addressing concerns at different cyclic points and stages of organizational change. ADKAR thus looked at the level of awareness and adoption while C-BAM looked at the situation of awareness and adoption. ADKAR examines how awareness leads to adoption; C-BAM evaluates how to manage the entire process to ensure

awareness produces adoption. ADKAR provide the framework for communicating, energizing, measuring and monitoring adoption progression. C-BAM focuses on assessing and addressing concerns at different cyclic nature and stages of organizational change. Both complemented each other in the navigational strategy to increase product (OSC, in this case) adoption.

This study thus draws on C-BAM and ADKAR models as the main theories employed in understanding the constituent elements of OSC adoption influencing factors.

Contributing to wider OSC adoption using theories, this study thus suggests three distinct approaches- appraising the existing state of offsite construction, evaluating the transition challenges and possibilities from the dominant traditional construction method to offsite construction method using change models, and how the first two can push the UKCI towards sustaining increased OSC usage through underpinning adoption theories. *See Figure 3.3*

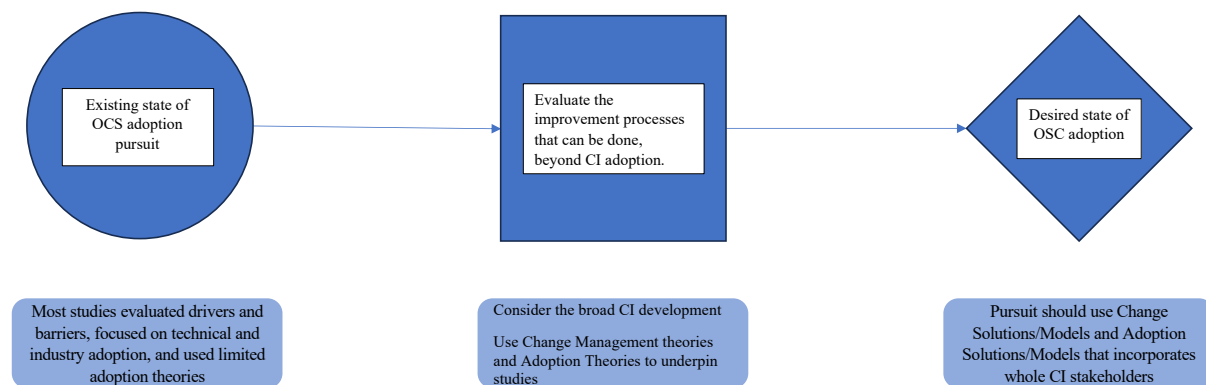


Figure 3.3: A theoretical Framework for Wider OSC adoption from a theory perspective.

Another observation from the reviews and the theories adopted for this study is that some of the influencing factors identified are external (‘inter’)-influences from outside the UKCI-many of which lie with adopters and the government policies. These external factors are mostly out of the control of industry practitioners and exert strong influences on adoption. The other

factors are internal (intra)-within the industry and can be controlled by industry practitioners, (e.g., design issues, assembly challenges, and such.). While this study is not categorising the factors along the internal-external dividing lines, (because, like the drivers and barriers, there are blurry areas within both), it is worth noting as some arguments in the body of this thesis may toe that inter-intra lines to buttress the points being made.

For the purpose of this research, abstract constructs or philosophical approaches in theory did not necessarily need to follow known frameworks owing to the exploratory nature of the study as highlighted by (Onwuegbuzie et al., 2010). Therefore, what is more applicable are approaches addressing theoretical issues that make up the backbone of this research as earlier noted and can support organic development of constructs. This is so because social or philosophical theories alone have proven not been able to address large scale emerging social trends or structures (Kawulich, 2009).

3.4 Summary

The theoretical underpinning for the study unpacked two major streams that are needed for wider OSC adoption in the UK- the construction professional, workers and allied bodies (all within the industry) and the other stakeholders (house buyers, investors, end-users, and such).

While the first stream needs to adopt OSC technology for production, the later needs to adopt it for continued production through ‘consumption’ (use). Current adoption pursuit and theories have largely focused on the industry stream while the ‘consumer’ stream seems marginalised in the adoption crusade. For there to be an increased OSC adoption, OSC champions and the UK government will need to look at the broader modern method of development and not just construction alone as suggested by Payne & Serin, (2023) who noted

that the use of the word ‘construction’ in MMC has made adoption efforts focus on the construction industry at the expense of those outside the industry but who the industry need for OSC adoption to increase.

CHAPTER FOUR

4.0 METHODOLOGY

Chapter Overview

The preceding chapters introduced OSC concept, research aim and objectives, and the various OSC adoption influencing factors and research perspectives presented by extant studies, including the theories used to frame this study. This chapter details the mixed method approach taken in conducting this research to achieve its aim. This chapter outlines and justifies the philosophical assumptions, design, approach, strategies and techniques taken in collecting, analysing and interpreting the research data. It elucidates the methodology and methods employed and concludes with rationales for the steps taken in effectively executing the Offsite Construction predictability possibility.

4.1 Research Methodology (Theoretical perspective)

Research methodology is the science of the simple step by step, process, method or technique that describes what tools and criteria are used to collect data, process data, measure variables and carry out analysis in a research work for any other researcher to be able to replicate the research (Murthy & Bhojanna, 2009; SHU Library, 2020). It is also the scientific strategy informing the choice and use of particular methods within the context of a particular research (Alele & Malau-Aduli, 2023). It addresses a justifiable study design, methods and procedure employed in a well-articulated research approach to answer the research question and satisfy the aim (Ayinla et al., 2019; Bergmann, 2023; Fellows & Liu, 2015; Holden & Lynch, 2004; Kirsch & Sullivan, 1992; Pole, 2007). The key make-up of this study's methodology is given in the *Figure 4.1* below and discussed thereafter.

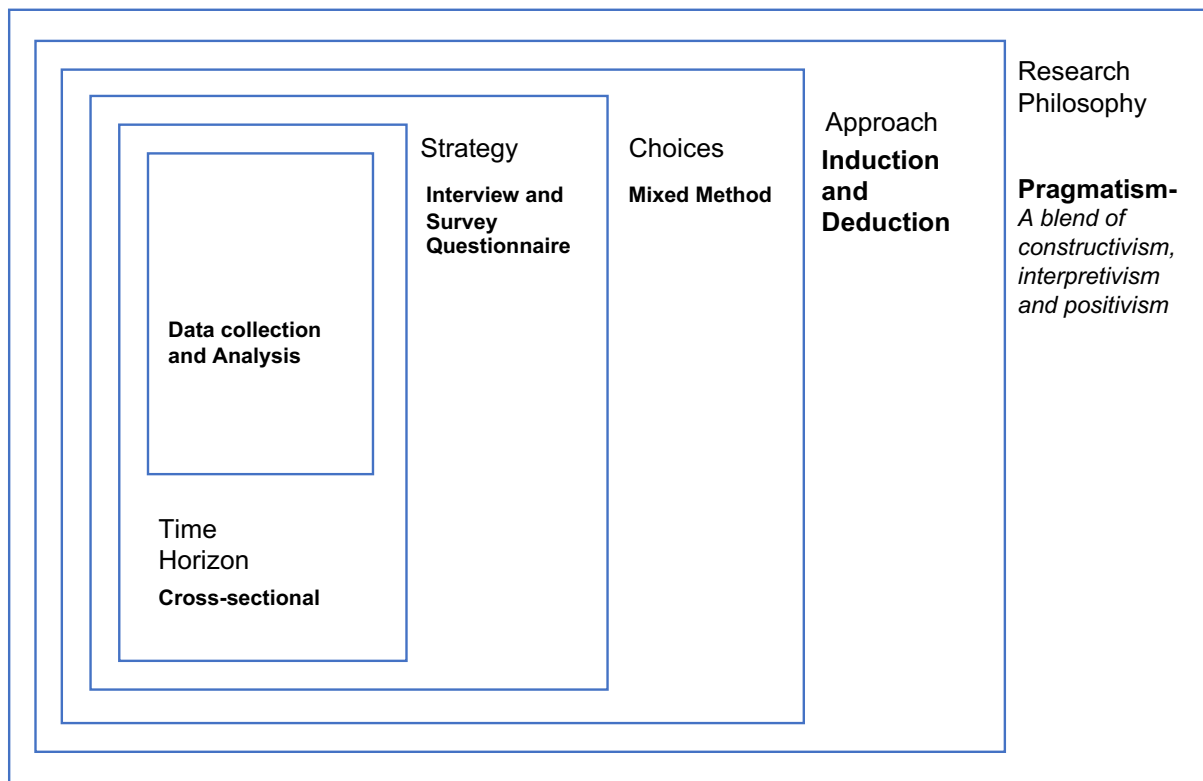


Figure 4.1: Research Diagram

Adapted from Saunders research onion diagram.

4.1.1 Research Philosophy

Research philosophy is the fundamental explanation for the overarching research framework—the *raison d'être* of the research inquiry (Mauthner, 2020). It is the lens through which researchers view the world and examines the methodological components of their research in deciding on which methods should be employed in data synthesis, collection and analysis (Alele & Malau-Aduli, 2023). It addresses the plethora of assumptions that attempt to investigate and explain how the research operates. Research philosophy is usually determined by the information being appraised, some of which may stem from the hypothetical debates and not just from the aim. However, ‘every research is expected to be carried out within a

framework of a set of philosophies’ and should utilize acceptable scientific methods (Madanayake & Ganiyu, 2018).

Also, research philosophy has many ‘isms’ as its paradigms which creates confusion as to which paradigm is being referred to and how that best fits the research discourse. Again, this issue leave researchers lost as to whether these ‘isms’ should be in theory or philosophy (Mauthner, 2020), [Cross-reference (Gilligan, (1982); Berger & Luckmann. (1966)]. Nevertheless, understanding and applying the appropriate research philosophy is crucial to clarifying research design, detect the effect of various research designs, extend existing ones and/or create new ones where necessary. The research philosophy, together with the applicable paradigms dictated the methodology adopted in this study. The research paradigms according to scientists, form the set of belief about how a problem should be understood and addressed. It is the way a social scientist describe his view of research (Madanayake & Ganiyu, 2018), [Cross-reference: Kuhn (1962), Guba, (1990)].

Research philosophy can be viewed from three distinct paths namely ontology, epistemology and axiology, and a fourth one-methodology as noted by Madanayake & Ganiyu, (2018,) and Alele & Malau-Aduli, (2023). Following that this research is applied research, aimed at addressing the challenge of low offsite construction adoption in the UK, a real and current construction and UK government challenge, it employed the most practical and acceptable research paradigms applicable to the study focus.

The study recognises social construction of knowledge as useful for stakeholder perceptions in the evaluation of OSC adoption pursuit. This is because OSC is a developing research area without a concrete base research facts on factors influencing its adoption and with lots of

lopsided subjective views, hence, requiring professional stakeholder's input for better understanding. With this, subjective idealism (interpretivism) becomes an important part of this work, and this aligns with the interpretivism philosophy. However, this study also intends to understand and measure the factors in terms of criticality; and measurement is a key feature of objective reality, aligning with the positivism stance.

The need to combine these two opposing paradigms necessitates the use of mixed method approach in this study. From the above explanations, the study's methodology is guided by its aim and objectives, showing the need to explore both qualitative and quantitative methods which could be opposing in nature. The most fitting paradigm is thus pragmatism as it allows a researcher to do the research in a way that best fits the study aim and answer the research questions. The pragmatic paradigm thus helps balance social dimensions (adoption behaviour, policy, skills, and the likes) and performance metrics (efficiency, cost, environmental impact assessment, and such).

4.1.2 Research Ontology

Ontology defines how reality is viewed or perceived, a study of being, a philosophical stance on the nature of reality and the existence of things or entities (Azhar et al., 2013) [CrossRef: (Easterby-Smith et al., 2012; Saunders et al., 2009; Crotty, 1998)]. It expounds on the nature of reality by trying to capture an entity(ies) as accurately as possible and by focusing on the assumptions researchers make in accepting something as true. The assumptions are believed to shape researcher's thoughts about a research topic, its importance, and possible approaches in answering the research question. Ontology is broadly viewed as idealism or realism. Idealism

looks at how opinions shape research decisions and realism examine how research is determined by measurable facts.

The ontological stance underpinning this research acknowledges reality as social constructs, shaped by cultural and social factors. As earlier noted, the geographical location of a study (project) influences the type and impact of adoption factor(s). This study is carried out within the UK geographical context. This location differentiates factors influencing OSC from those of other locations, thus creating a research examination context.

It is understood that some other locations have outperformed or underperformed the UK in terms of OSC adoption, therefore the location context brought about subjective idealism- that the reality in this case may be socially constructed or influenced. Also, since the argument about UK OSC adoption is on 'how much has been adopted against how much should have been adopted', the ontology stance is also influenced by measurable factors accountable for its low-level state, thus sharpened by objective realism. The subjective idealism is particularly linked to subjectivism (interpretivism)- a social realism stance that argues that OSC adoption is shaped by stakeholders' perception, cultural attitudes and regulatory frameworks while the objective realism is linked to positivism (Bendi, 2017). Therefore, the most applicable ontological stance for this study is critical realism (linked to pragmatism) because OSC adoption is influenced by both measurable objective factors (technology, supply chain, design and construction, and the likes) and observable subjective interpretations (market readiness, awareness, perception, and such) (Bhaskar, 1975, 2008).

4.1.3 Research Axiology

Axiology is the philosophical stance that deals with value, especially what is considered worthwhile or valuable in the context of research (Heron, 1996). It explains the role and importance of the processes the researcher considers as values in arriving at the research outcomes (Guba & Lincoln, 1994). It presents an understanding of the researcher's values and roles in the research. It deals with how right or wrong the process adopted is, measuring the level of development and the types of perceptual biases in the process (Mertens, 2010). It answers questions relating to upholding the rights and respect of research participants, ethical principles that guided the research, the cultural and intercultural issues considered and risk minimization to mention a few. Importantly, it addresses the values the research contributes to knowledge and a society.

This research addresses housing shortage (through rapid housing provision possibilities) and environmental sustainability (through minimising waste generation and contribution to achieving Net-Zero carbon emission). The sampling methods employed in the interview and survey and the demographic representation achieved address most issues relating to axiology by ensuring UKCI-professionals (for interviews) and UKCI-stakeholder's project perspectives (for survey), evidence-based guidelines, attention to disparities, thus ensuring fairness, equity and avoidance of assumptions. It achieved the study outcome by adopting a cross-sectional approach, following ethical rules laid down by the University of Hertfordshire and UK HEA, and minimised foreseeable risks through different risk mitigation measures. For instance, the researcher's position in the interview was moderation and data extraction in line with the research aim, maintained a complete objective position in the survey questionnaire, and also

ensured no question is a double barrel question, i.e., no question is asking information for two issues at once.

4.1.4 Definition of other mixed-method terms used in Research Philosophy

Positivism: This is a philosophical stance grounded in the that reality is objective and can be measured through observable measurable phenomena (Creswell & Creswell, 2018). It supports the use of structured methods such as experiments, surveys and statistical modelling to test hypothesis and uncover causal relationships.

In this study, positivism aligns with the quantitative phase, particularly the evaluation of the criticality influence of factors on adoption, and in developing models for adoption prediction likelihood based on the objectively measured critical factors.

Interpretivism: It the philosophical stance that holds the belief that reality is socially constructed and subjective. It believes reality is best understood through the meanings and experiences of individuals (Schwandt, 2000). It emphasizes context, depth and the co-construction of meaning between a researcher and participants.

In this study, interpretivism underpins the qualitative phase, particularly the interview section and qualitative data analysis using content and thematic analysis. This allowed understanding how UK construction industry professionals perceive OSC drivers, barriers and behavioural adoption issues from their experiential and organisational contexts.

Pragmatism: It is a problem-driven philosophy that priorities ‘what works’ in addressing real-world issues by lending methods, perspectives and data types (Morgan, 2007, 2014). It

advocates methodological pluralism and flexibility to gain a fuller understanding of complex phenomena rather than committing to a single epistemology.

In this research, pragmatism serves as the overarching philosophical paradigm that justifies the mixed methods approach- triangulating evidence from literature, interview, surveys and ML to attempt holistic evaluation of OSC adoption. It recognises the value in combining both subjective insights with objective data to produce a contextually rich and practically useful knowledge on OSC adoption.

Summarily, research philosophy (epistemology) addresses what is knowledge, ontology addresses what is reality or truth (idea), axiology addresses approach that mitigates biases by ensuring the researcher maintains a role that exhibits value addition during the research. Following the inadequacies of each stance of research philosophy, ontology and axiology to fully satisfy the overall research aim through the research objectives and questions, it turns out that to achieve the sole aim of the study, the research philosophy that satisfied the overall aim neither lend itself to a interpretivism or positivism stances. The presence of elements of these paradigms agrees with the thoughts of Cohen et al., (2007) that mixed method approach can exhibit multiple paradigms. Therefore, what is more applicable under these conditions is pragmatism- a paradigm which allows a researcher to use the most suitable method to achieve the research aim. It neither tries to find what is ‘truth or idea’ nor what is ‘reality’, but what ‘works’, just as this study is neither seeking ‘truth’ or ‘reality’ about OSC but what can favour increased OSC adoption in the UK. Moreover, pragmatism fits properly into a social setting where there are complex social phenomena as in the case of OSC in the UK where influencing factors are reported as both drivers and barriers, without clear distinctions. So, a pragmatic

research philosophical stance provides a balance to the mixed method approach employed in this study by focusing on the practical application of knowledge to create a research position that is both theoretically sound and applicable to real world setting and solves a real-world problem. Several authors have recommended pragmatic stance as an ideal philosophical stance for mixed method research e.g., (Alele & Malau-Aduli, 2023, Pole, 2007; [Cross reference: (Tashakkori & Teddlie, 2003, p. 677)] among others.

4.2 Research Approach

Research approach is the broad plan or strategy adopted when conducting research. It is essentially the blueprint guiding all methodological decisions, ensuring the research process aligns with philosophical stances and objectives. It defines how knowledge is sought and structured. It can be viewed as the bridge between research philosophy and research methods. The three main types of research approach commonly recognised are qualitative, quantitative and mixed method approaches. However, there are approaches (logical pathways) to research approach, namely deduction, induction and abduction. These are three principal approaches to reasoning and knowledge synthesis in research and they inform different stages of research processes (Ketokivi & Mantere, 2010; Timmermans & Tavory, 2012). They are highlighted below:

Deduction: It is the extraction of data from an established theory, hypothesis or extant article. The information extracted is then tested against an empirical data (Blaikie, 2007). Deduction is usually explanatory.

In this study, deduction first occurred at the literature review stage where reported factors influencing OSC adoption were deduced from extant studies. Additional deductions were made at the quantitative phase where findings from SLR and interview triangulation were operationalised into constructs with variables for survey questionnaire development. Further, feature selection and machine learning methods were used to establish critical OSC influencing factors from the surveyed population.

Induction: It is the synthesis of knowledge from a specific observation to a broader generalisation. It involves developing the themes or patterns from data, and it does not necessarily have to begin with an hypothesis or a framework (Creswell & Poth, 2016). Rather, knowledge or pattern can organically emerge from data, and in this case, participants response. Induction is more exploratory in nature.

In this study, induction informed the qualitative phase and occurred at the interview stage where rich information was extracted from industry professionals and themes were developed from the lived experiences of UKCI professionals on OSC adoption.

Abduction: Abduction bridges use of induction and deduction in reasoning by iterating between theory and data to provide the best explanation for a phenomenon (Timmermans & Tavory, 2012). It has been found especially useful in mixed method research approach, enabling research to interpret ecstatic or inconsistent findings through deeper theoretical reflection and critical realist underpinning.

Following the mixed method approach, the pragmatic philosophy and the critical realist stance adopted for this study (*See Section 4.1.1*), the most suiting logical approach for this study is

abduction. Abduction reflected in this study through the combined theoretical frameworks employed in approaching the ‘inter’ and ‘intra’ adopters’ streams in wider OSC adoption pursuit. Allowing for a balance between theory testing and theory building. Precisely, CBAM and ADKAR enabled identifying underlying mechanisms that helped explain the complex OSC adoption dynamics by emphasising on adoption beyond professionals and allied professionals’ adoption alone. Also, this led to extending ADKAR model to create $ADKAR \Rightarrow A$.

4.2.1 Definition of other mixed-method terms used in Research Approach

Triangulation: It is the combination of factual information from different sources to build a single source of truth (Carter et al., 2014). It involves the use of multiple methods, data sources, theories or investigators to study a single phenomenon with the goal of enhancing validity, credibility and comprehensiveness of a finding by cross-verifying results from different angles (Denzin, 2017; Patton, 1999). Triangulation can be methodological, data (source or analytical method), theoretical or investigator triangulations (Carter et al., 2014; Thurmond, 2001). The triangulation noted above is data source triangulation-used to develop a measuring instrument. The study also used theoretical triangulation (CBAM, ADKAR and RIBA-PoW in enhancing the understanding of OSC adoption progress), methodological triangulation (interview outcome and survey outcome in identifying factors influencing OSC adoption) and data analytics triangulation (Multi-class and Binary Classification, Mode and KNN missing data imputation, Random State iteration and using multiple models in identifying and establishing the critical adoption influencing factors). Employing triangulation decreases, negates or counterbalances the limitations and reliance on a single source or strategy and so increases the interpretability of the findings (Thurmond, 2001).

Operationalisation: This is a technical and critical step used in transforming inductively generated insights into a measurable, observable variables within a research design (Bryman, 2016) that can be tested and quantified deductively (Adcock & Collier, 2001) and can be systematically explained abductively through integrated modelling and theory (Punch, 2014).

This study used operationalisation to transit from qualitative exploration to quantitative analysis by using the themes generated to develop a structured Likert scale measuring instruments containing constructs and variables, thus allowing for statistical measurements, feature selection and model development to achieve the study aim.

4.3 Research Choice (The Mixed Method Approach)

This study used an exploratory mixed method approach (*Refer to Section 1.11*), employing both the interview (qualitative) and the survey (quantitative) approaches (Choy, 2014; Creswell, 2003; Creswell et al., 2003). This means it neither lends itself to the interpretivism nor positivism paradigms (Creswell, 2003; Ellis & Levy, 2009). What was more applicable in this research is the pragmatic approach (Fellows & Liu, 2015) because it allowed the use of both qualitative and quantitative methods on a research as suiting to the research aim (Alaka et al., 2016; Brannen & Moss, 2012). It further gives room for the study to find and use the most convenient approach to carry out this research work to achieve the set aim (Pole, 2007; M. Saunders et al., 2009).

Owing to scarce and lopsided OSC knowledge (Agapiou, 2022; Cai et al., 2022; Zhang et al., 2024), the fact that OSC is being re-introduced into the construction mainstream (Razkenari et al., 2020; Wuni & Shen, 2022), and that it is just gaining traction due to modern technologies,

practices and urgency in addressing housing shortages (Jin et al., 2018; Nadim & Goulding, 2010; Wuni & Shen, 2020b), it was crucial to engage the UK construction professionals in inducing current knowledge on OSC influencing factors through interview. It was equally imperative to conduct a survey for this research (Anguera et al., 2018; Onwuegbuzie & Hitchcock, 2015) to measure the influence degree of identified OSC adoption factors within the UKCI. Through extant literature, scholars opined that where there are not many articles on a subject matter being researched, qualitatively researching the area provides rich information on the subject under view. (van Esch & Esch, 2013; Vasileiou et al., 2018). This is because qualitative research allows delving deeper with those being interviewed and clarifying grey areas beyond what quantitative approach would provide (Hammarberg et al., 2016; van Esch & Esch, 2013).

The quantitative approach measured the criticality of the identified factors using advanced statistical approach (which are adjudged very reliable, (Brown, 2024)), and not just basic assumptions or empirical conclusions (Gregar, 2014; Queirós et al., 2017)).

The mixed method choice thus employs the strength of both strands and complement the weakness(es) of each (Pole, 2007; Queirós et al., 2017). Additionally, mixed method tests whether the strands' results converge (corroborate), elucidates grey areas (completeness) or affirms the integrity of the findings (credibility) (Bergmann, 2023). Thus, combining qualitative and quantitative methods allowed the research to run without being fixated on either quantitative or qualitative hinge solely (Fellows & Liu, 2015; van Esch & Esch, 2013).

4.4 Research Method (Strategy)

Research method is the practical step-by-step procedure taken to collect and analyse data, premised on the methodology adopted. It is research philosophy in action, a metaphysical practice to convey ideas and ways of doing philosophy (Mauthner, 2020). It describes the chosen technique or procedures adopted in gathering and analysing the research data relating to the research questions and hypothesis presumed (Madanayake & Ganiyu, 2018).

The unit of analysis is Offsite Construction adoption in the UK, while the unit of observation is UK construction industry professionals and the unit of measurement is Offsite Construction projects. The unit of analysis often refers to the main entity or object about which a researcher draws a conclusion. It is usually the focus of the study- who or what the study is ultimately about. The unit of observation is person or object from which data is gathered. It describes ‘who’ or ‘what’ is being studied, observed or measured in practice. It evaluates the entire subject under investigation (Trochim, 2007). The unit of measurement evaluates the entity from which the measurement is taken. The unit of measurement defines how a concept or variable is measured while unit of analysis guides the analysis, data result interpretation and what is concluded upon (Kumar, 2018).

The data types used for this study are secondary data collected from literature review and primary data through interview and survey questionnaire. The research is a mixed method, employing both interview and questionnaire to generalise findings. This study used interviews to collect qualitative data and survey questionnaire to collect quantitative data for its mixed method approach. Interviewing in research can be structured, unstructured or semi-structured (Gill & Baillie, 2018; Patton, 2002) while survey questionnaires are commonly reported to be

structured or unstructured (Singh & Singh, 2024). This study used semi-structured interview and structured survey questionnaire for data gathering. **Figure 4.2** below gives a diagrammatic breakdown of the steps taken in the research approach and in arriving at the thesis findings and conclusions.

The study developed an interview protocol from a globally extracted factors influencing OSC adoption using SLR of articles. The interview identified these factors' relevance to the UKCI. Its outcome was triangulated with UK-focused SLR to develop a quantitative instrument used to measure the factor criticality to OSC adoption in the UK. *See Figure 4.2.*

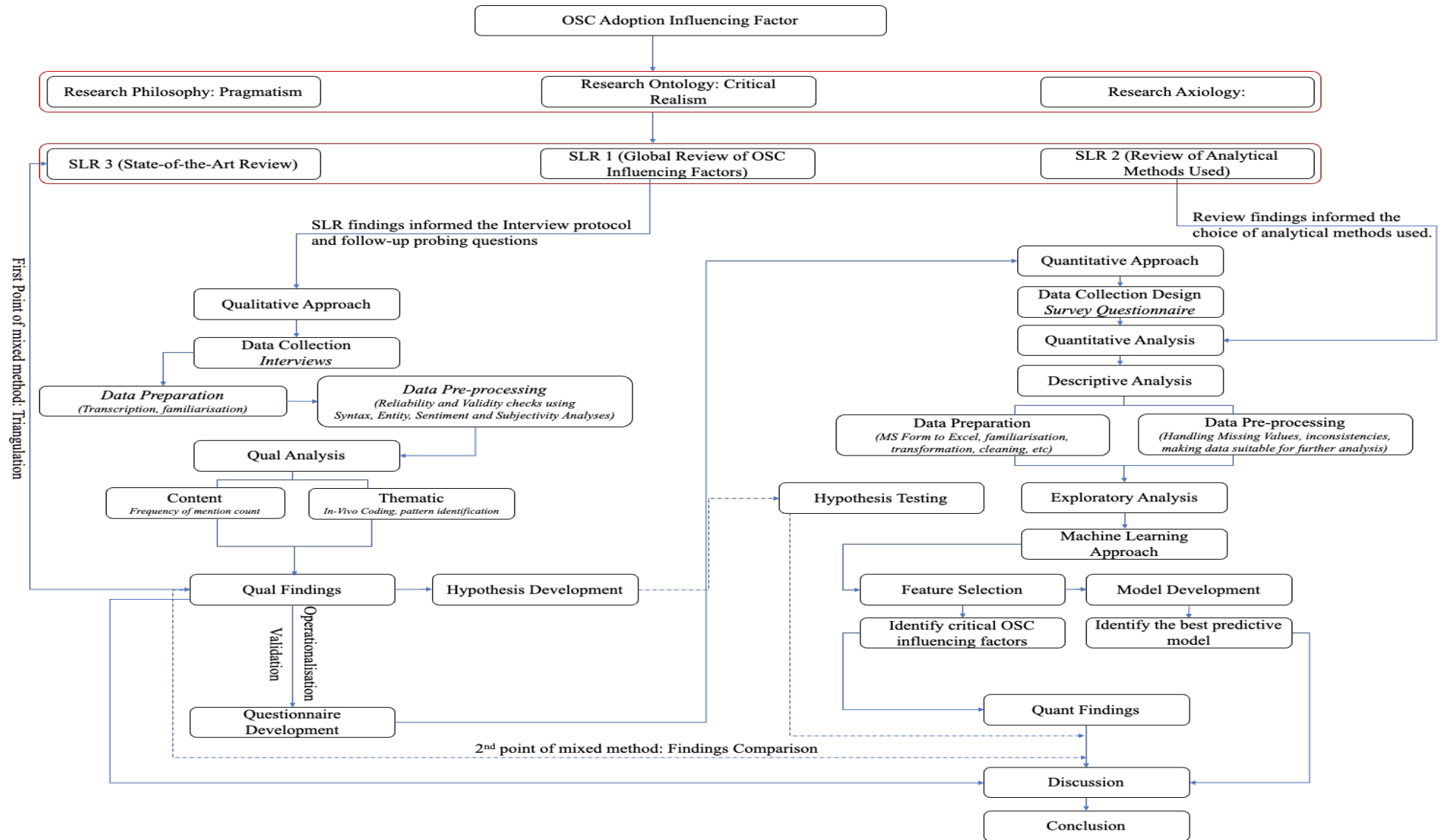


Figure 4.2: Research Methodology

4.4.1 Data Synthesis

The data synthesis approach for this study took few steps, namely, systematic review of literature, development of interview questions, and conducting interviews to induce underlying OSC influencing factors (*See Figure 4.2*). Further, the induced factors, which are primarily issues, factors and themes identified from the interviews, triangulated with findings extracted from the UK-focused systematic reviews outcomes, was operationalised into a survey questionnaire administered for quantitative data gathering (Pole, 2007). The questionnaire responses were analysed for critical OSC influencing factors using a combination of statistical models in a multi feature selection task. Outcomes of the analyses extracted the most critical influencing factors and developed predictive models using Machine Learning algorithms after training, validating and testing the models. The final phase in the analysis outcome, after extracting the critical OSC influencing factors was developing OSC adoption prediction models and selecting the most suitable model that favour predicting the possibility of increased OSC adoption within the UK construction industry.

First, a comprehensive systematic literature review was carried out to establish existing OSC influencing factors and how they impact the level of OSC adoption in the UK and other nations of the world (Moher et al., 2007; Schlosser, 2006). The expansive systematic literature review was done using Scopus and Google Scholar engine searches. (*See SLRs in chapter 2* for details).

Secondly, factors deduced from literature review were used to develop interview questions for inducing current issues and knowledge on OSC from construction industry professionals. Oral interviews were conducted to establish the state of existing factors reported by academic scholars and induce (new) issues bothering OSC adoption (Bloomberg & Volpe, 2015;

Nickoson & Sheridan, 2012). Using content and thematic analysis, the outcomes of the interview were analysed for frequency of mentions and patterns, respectively. The interview and SLR 3 outcomes were triangulated to avoid biases and reliance on single data source. The triangulation process evaluated theoretical, methodological and practical influencing factors in comparison with interview outcomes (Walker, 1997, [Cross-reference: Hammersley and Atkinson (1983, p. 199)]). The triangulation exercise and result informed the constructs developed in the survey questionnaire administered. The factors induced from the interview with construction industry professionals and SLR 3 (a UK-focused review) were operationalized to develop the 5-point Likert scale survey questionnaire (Ellis & Levy, 2009; McKinney, 2015; Schlosser, 2001) that was administered to construction industry stakeholders to gather quantitative data in analysing factors influencing OSC adoption.

The questionnaire was structured to have multiple-choice questions and 5-point Likert Scale questions (Fellows & Liu, 2015). This questionnaire was intensively piloted by a sample of the proposed respondents (Palinkas et al., 2015) before administering it electronically to the larger UKCI stakeholders. A survey respondent is defined as a construction stakeholder who may be an architect, engineer, quantity surveyor, builder, contractor, investor (private or public, e.g., government), client or end-user with OSC project experience. Respondents were purposively selected from the diverse groups of CI-professional and allied industry stakeholders to give a holistic view and better representation of the targeted population. The questionnaire, designed to last an hour, was targeted at a minimum of 500 responders within 150 days. The questionnaire eventually lasted 269 days, returned 337 responses with average response time of 58 minutes 56 secs. The questionnaire responses were exported to excel for detailed data explorative and descriptive analyses. SPSS was used for further statistical analysis like

reliability tests (Little et al., 2000). Exploratory data analysis was done in Python using VSCode environment. Finally, Machine Learning was used to develop models that can help predict the critical factors that favour the possibility of OSC adoption within the UK construction industry.

4.4.2 Qualitative Approach

Historically, a large percentage of previous studies on OSC adoption have deployed quantitative research approaches according to Blismas & Dainty, (2003) to identify different factors responsible for low OSC adoption. More recently, a systematic review of methodologies used on offsite manufacturing research by Ehwi et al., (2022) affirms this position and the continued trend. Creswell & Creswell, (2018) also share this view in social sciences, stating that quantitative studies dominated social science studies till late mid-20th century and interest in qualitative studies, alongside mixed method approach, gradually picked up later mid-20th century. These quantitative studies alone failed to provide a rich contextual account of how social dimensions and construction of knowledge limits OSC adoption and the boundary conditions accountable for low OSC adoption level.

According to Blismas & Dainty, (2003), *“there remains a paucity of critical discourse within the construction management research literature about the impact of such approaches on the depth and rigour of the resulting analyses”* Also, Queirós et al., (2017) noted that this is unsurprising as a quantitative approach is unsuitable for understanding emerging research phenomenon in-depth in its context as it does not answer how and what questions. For instance, in (Cai et al., 2022) account, the adoption mechanism for OSC by firms/stakeholders has not been clearly understood, thus, hindering overall OSC adoption, thereby suggesting the role of

a qualitative approach. Gleaning from Blismas & Dainty (2003) and Ehwu et al., (2022), too many studies within construction management research relied on quantitative approach and the limited use of qualitative approach highlights the imbalance and disconnect between reported findings and the underlying interactions among key factors, potentially overlooking the complexities of construction management practices.

This study employed qualitative approach to extract rich, appropriate, current and applicable OSC influencing factors within the UKCI context to support this in understanding and identifying critical OSC influencing factors in the UK. A qualitative research perspective is more phenomenological than narrative. In this approach, the interviewees were requested to describe their ‘lived’ experiences of OSC rather than studying the lives of the interviewees or asking them to provide a story of their lives around OSC (Creswell & Creswell, 2018) [Cross Ref Riessman, (2008); Clandinin & Connelly, (2000); Giorgi, (2009); Moustakas, (1994)]. The study thus focused on understanding how social constructs limited OSC adoption and the boundary conditions responsible for adoption level in-depth in the context of UKCI (Cai et al., 2022).

Developing interview protocol

To achieve standard and valid interview approach, an interview protocol was designed and developed for the interview process. Factors identified from SLR 1 were used to develop a semi-structured interview protocol. The interview protocol asked only two (2) open ended question on OSC, thus giving room for issues to emerge organically from the conversations. However, following recommendations by some literatures (Döringer, 2021; Gill & Baillie, 2018; Husband, 2020), probing questions have been outlined from SLR 1 to drill deeper and

consolidate the points unveiled by interviewees following the direction of their responses. It ensured alignment with the research questions, aim and objectives, including reported divergent opinions of factors influencing wider OSC adoption such as cost, time, efficiency. It also ensured enquiry-based conversation, drawing experiential facts from respondents (Hamzah & Ismail, n.d.). The interview questions avoided any leading questions. The interview protocol was developed after extensive literature review on OSC adoption factors and related issues. It ensured the use of simple and clear, yet professional tenses and terms in asking the questions before being piloted and submitted to ethics committee for approval. See *Appendix 4* for interview protocol details.

Piloting Interview Protocol

The interview protocol (questions) went through several refinement and piloting before it was administered. This ensured a decent looking, concise, and easily comprehensible protocol that can achieve the research aim. Strategies for the Interview Protocol Refinement (IPR) ensured the questions developed and asked during the interview process, including follow-up questions, are in line with the aim of the research and consistent with the objectives (Castillo-Montoya, 2016). The IPR also ensured the questions are enquiry-based questions, capable of generating rich and in-depth conversations through employing the rules of social conversations and asking variety of follow-up questions according to Castillo-Montoya, (2016). The IPR ensured the protocol was piloted in line with qualitative rules and received adequate feedback that ensured best research practices (Malmqvist et al., 2019). The piloted interview protocol was submitted to UH's ethics committee for approval.

Ethics approval

The submission addressed and satisfied UH's ethics requirement in the areas of anonymity, privacy, data storage, freedom to decline participation at any time amidst other ethical issues. Approval was obtained from University of Hertfordshire Social Sciences, Arts and Humanities Ethics Committee with Delegated Authority (SSAH ECDA) with ethics number BUS/PGR/UH/05327.

Obtaining Interviewee's Consent

A consent form for potential respondents to sign and return, obtained from the university, was updated and sent alongside the interview protocol. The consent form is part of the school's ethics requirement for conducting research that involve humans. This ensured the interview obtained an informed consent from interviewees before proceeding with the interview (Husband, 2020). Though not all were comfortable signing the consent form, those who could not sign the form consented via email, while some others declined the call. This also, could have influenced the number of respondents who took the interview. While twelve respondents consented and took the interview, just six (6) of them filled the consent form and returned it. The other six consented (via email response) without committing themselves to the form for personal reasons which were not disclosed to the researcher.

Respondents were notified about recording the interview meetings in the protocol and reminded of same at the start of the meeting, thus obtaining their approval before recording the meeting. The protocol also notified the interviewees that they can withdraw from the interview at any time or decline any questions with which they were not comfortable.

4.4.3 Qualitative Sampling

The sampling method employed for the interview was purposive sampling- focused on construction industry experts who have a good knowledge of both the construction industry and offsite construction (Rahimian et al., 2017; Vasileiou et al., 2018) before adding snowballing. Purposive sampling was selected as the preferred sampling approach because it affords "information-rich" cases that can provide deep, detailed insights relevant to the research questions, beyond what statistical generalizability would provide. Wuni & Shen, (2023) attested to the need to resort to expert opinion for hands-on project knowledge on OSC owing to project data absence. First, a list of OSC companies was gathered through Kier construction website, a leading MMC company in the UK (KIER, 2021). The list was later put aside because it was made up of, if not only, manufacturers and that may distort the objective of the research which was to extract professionals' knowledge and insight on OSC adoption level and factors, and not just of manufacturers. This again highlights the absence of comprehensive OSC database that stores OSC professionals' details from which researchers can draw sample population for research works.

A new approach was adopted and that was highlighting the professional areas within the construction industry to be contacted. The professionals listed to be contacted included Architects, Civil/Structural Engineers, Mechanical, Electrical and Plumbing (MEP) Engineers, Suppliers, Marketers, Logistics personnel, Planners and Investors. The interviewees were majorly sort out through LinkedIn and industry reports cited by academic articles. A few others were identified through a construction community group the researcher belongs to.

Selecting Respondents

The sampling frame is drawn from lists of offsite construction directories such as offsite expos (like

https://issuu.com/radarcommunications/docs/offsite_mag_100pp_iss_28_web/s/12707317

and https://issuu.com/radarcommunications/docs/offsite_expo_2021_showguide_web), offsite

alliance website (<https://www.offsitealliance.org/>), offsite construction publications (like

Offsite Magazine, BuildOffsite E-Magazine, Offsite Architecture, ConstructionNews,

pbctoday), offsite groups social media handles (such as #kier,

#mbi, #officebuildings, #moderndesign, #mmc, #portablebuildings, #mobilehomeinvesting,

#mobilehomes, among others). Offsite expo was considered because it is the single largest

event and body that brings together most offsite related construction firms in a single event.

Offsite Alliance and BuildOffsite were considered because they are the big umbrellas under

which most of the other offsite bodies operate and are regulated. With these few mentions,

among others, the study was set in consonance with its aim and objectives. Personnels from

the highlighted groups were sought through their member list and profiles. Personnels with

profiles aligning with the study aim were carefully drawn as potential interviewees and

contacted. The researcher also joined Supply Chain Sustainability School where a handful of

construction professionals working on Offsite Construction projects, research and

developments converged. Personnels, members and event attendees with profiles matching the

study aim and objectives shadowed (through their social media handles), were carefully

selected and contacted.

In selecting the respondents, bias was an issue considered and carefully eliminated to the barest

minimum by ensuring those with the right experience profile on both general construction and

modern methods of construction were contacted for the interview from among the list of those considered. Some of the **criteria** the respondents fulfilled were having the UK construction projects experience, having knowledge of both OSC and general construction, should have considered or been involved in one or more OSC projects either at preliminary/design phase, execution phase or both (Walker, 1997). The selection ensured those considered for the interview have UK offsite construction project experience or knowledge. The selection process does not claim to have employed the best candidates for the interview, rather it maximized the best available candidates it found most suitable for the research purpose within the research scope. The respondents were notified ahead of what sort of interview they would be taking, with other relevant details required for smooth interview period and experience (*See Appendix 4*).

A total of eighty-one (81) industry professionals were listed to be contacted. Over a half (45) of those listed out were contacted. Twenty-two (22) people did not respond to the call. 3 people declined taking the interview, another five (5) referred the interview to their colleagues because OSC is not their area of strength. About fifteen (15) among those contacted accepted the invitation to take the interview, but after several follow up mails, only eight (8) people fixed a date and took interview. Three (3) people fixed date but did not take the interview while four (4) accepted but did not fix a date. Due to the low response rate, the interview process employed snowballing through some of the interviewees (Darlow et al., 2021). This added four (4) more respondents. In all, twelve (12) interviewees eventually took the interview. The overall interview response rate was 26.67%.

Saturation, often noted as the comprehensiveness of data collection, collation and analysis (Oseghale et al., 2024) was reached at the tenth interview. At the twelfth interview, no new factors were observed but mere emphases on earlier mentioned factors and OSC adoption issues, thus, ensuring and confirming no new information was emerging. The twelve interviews used were consistent with scholars who argued that 11-17 interview is adequate for a mixed method research. (Nickoson & Sheridan, 2012; van Esch & Esch, 2013; Vasileiou et al., 2018). Also, a good number of authors have recommended 12 number interviews as sufficient for a mixed method scholarly work (David & Hoffman, 2018; Galvin, 2015; Marcus, 1986; Saunders et al., 2015; Vasileiou et al., 2018).

Additionally, not many CEM articles studied were found to have interviews with more than twenty interviewees. While some submissions have been found to have a very large number of interviewing, e.g., (Galvin, 2015), majority of such related reports had 8-12 number interviewees in a group of 4-8 for such research works. The number 12 is therefore considered adequate for this qualitative research in consonance with internationally accepted minimum number of interviews for a research purpose according to the authors noted above. This is also in tandem with some earlier scholars within the construction industry and more precisely on OSC, who have carried out qualitative research to determine the factors influencing OSC adoption. For example, Saad et al., (2021) used ten (10) interviewers for his qualitative research interview, while Luo et al., (2020) used four (4) interviewers for the mixed method research focused on Supply Chain Management in Honk Kong, Feldmann et al., (2022) used twelve (12) interviews to explore barriers to using Modular construction from a developers' perspective among others.

Other constructs used to justify the number of interviews adequate for a qualitative research are saturation, experience of the researcher and quasi-empirical foundations (Palinkas et al., 2015). **Overall**, when saturation was observed at the tenth interview, with no new insights emerging after the twelfth, the interview process was deemed adequate to progress the research with.

4.4.4 Interviewing

The instruments used for the interview maintained reliability and validity measures through asking same and consistent open-ended and follow-up questions developed from literature review across the interviewees as recommended by Meadows, (2003). To ensure the interview is of quality, the questions developed ensured credibility, consistency, applicability and transferability. This is achieved by the interviewer maintaining neutrality with little or no interference to the respondents during the process (Hamzah & Ismail, n.d.) in addition to earlier noted measures noted in piloting and IPR.

The interview design employed funnel approach (Bergmann, 2023), commencing with introduction and stating the interview purpose before going on to the more general demographic questions relating to respondents construction experience. It then delved into the two (2) open questions about factors influencing OSC adoption, followed up with semi-structured probing questions. The interview was scheduled to last one hour. See interview meeting agenda below:

<i>Introduction</i>	<i>3mins</i>
<i>Purpose of interview</i>	<i>2mins</i>
<i>Interviewing</i>	
<i>Industry Experience</i>	<i>5mins</i>

<i>Study focus (open ended question)</i>	<i>25mins</i>
<i>Follow-up discussions</i>	<i>20 mins</i>
<i>Debriefing/Final remarks</i>	<i>3min</i>
<i>Appreciation/ Closing</i>	<i>2mins</i>

The questions were asked slowly, clearly, and reasonable audibly. Where respondent expresses not being clear on a question, such question(s) were repeated and expatiated upon. Also, where the response provided seem not to be adequate or sufficient for the research purpose, such points were further probed (Afolayan & Oniyinde, 2019). The interview process was allowed to go with the flow of the discussion (Robinson, 2020) based on the response of the interviewee and in line with the research aim and follow-up questions. The follow-up probing questions asked the interviewees were not all in the same sequence aside the opening open-ended questions asked them all. But the same probing questions were asked when similar unclear issues were raised.

A total of twelve interviewees, covering most sections of the industry practise participated in the exercise. The interviews were held via zoom and MS Team, lasting averagely fifty-five (55) minutes. The interview was recorded via zoom (audio-visual) and office 356 (audio and text) (Gill & Baillie, 2018; Robinson, 2020) and auto-transcribed for further cleaning and editing. The exercise was concluded by thanking the participants for their time and contribution to the research. They were also asked if they had final words or anything they felt was omitted during the discussion. The participants were allowed to debrief satisfactorily before the interview was closed.

4.4.5 Interview Data Analysis

The longest interview took one hour, twenty-three (1 hr 23) minutes while the shortest took forty-eight (48) minutes, and averagely fifty-five (55) minutes. The analysis process employed the content and thematic analysis principles which are data collation, data familiarization, initial coding, categorisation, review and refinement of categories, defining and naming themes, mapping and analyzing themes, drafting the report and discussing its findings. To maintain anonymity in reporting the interview outcomes (Saunders et al., 2015), respondents were tagged R1, R2, R3...R12. *See Chapter 5* for detailed Interview Analysis

4.4.6 Interview Validation

The interview respondents were again contacted via email for validation exercise. Earlier before then, they were updated on progress with the interview analysis without sharing any of the outcomes with them. When the interview analysis was fully completed and tabulated out, they were contacted for validation via email with an availability poll. The validation exercise was targeted to be a focused group meeting, which could have fostered deeper interaction of the interview outcome beyond personal experiences and solidify concession on the interview results (Adams & Cox, 2008). A poll to check the interviewees' availability for a focused group validation exercise was therefore developed in Doodle, with 3 days option and 3 time slots for each day. One of the twelve interviewees was no longer accessible because he has changed job. An auto-email response provided this information. Another responded that he was bereaved and cannot be available for the validation exercise. Two interviewees responded to the invite and picked dates from the polls. The remaining eight did not responded to the polls invite. After some follow-up email, four people responded and declined the invitation. Two did not respond still while two fixed a date. So, the validation got four respondents. It unfortunately turned out

the time slots selected by them did not converge. This experience has been noted as one of the limitations of focus group meeting (Drescher & Edwards, 2019; Gill & Baillie, 2018). An appeal email was sent to each to see if any could move date and time to enable hold a focused group validation, but that still did not work. Therefore, the validation exercise which was planned to be synchronistic was eventually carried out asynchronously with individual respondent.

The interview validation exercise appraised the documented outcome of each respondent's interview analysis and cross-validated it with the interview analysis outcomes of other interviewees. The validation exercise had a good space of time from the interview period to see if new or improved issues would emerge. During this period, the third SLR and the unreported grey SLR earlier mentioned, both of which are UK focused were done. Based on the interview analysis outcome, further strategies such as cross-validation were applied during validation exercise to establish the findings from all respondents in addition to the reviews following the review outcome.

Validation result

The validation exercise also checked if there are any changes or improvements to the factors discussed during the interview since there was almost eighteen (18) months gap between interview and validation. It turned out a few improvements have taken place which further confirms the interview outcome that OSC adoption within UK is gradually improving and gaining positive attention. Some improvements noted are that funding is now being favoured by OSC's sustainability positives, and effort is made toward corporate standardisation to mention a few points.

The validation exercise further affirms some of the interview analysis and findings, adding some issues have not significantly improved and some other deteriorated further according to the interviewees. For instance, CI pipeline of work does not yet accommodate automation fully. Also, there is liquidation of more module manufacturing companies (H+H Ltd, 2024; Stein & ConstructionNews, 2025) due to long planning approval permission duration and huge upfront capital (Bamford, 2024; Stein & ConstructionNews, 2025). Within a space of three years, (2021-2023), a total of twenty-one (21) MMC businesses went insolvent as at mid 2023 (Akerlof & ConstructionNews, 2023) as against fewer companies that went burst in previous years. April, 2024 MMC News publication (Bamford, 2024) further affirms why OSC adoption is still slow. Also, to increase OSC adoption, the public, and not just industry professionals, need to be convinced to embrace OSC. The call for withdrawal of funding for OSC adoption at the parliament (Ridings, 2024) with reference to investment in OSC as a waste of tax-payers money among others owing to absence of OSC project data also set some discouragement in.

Thus, the use of validation and triangulation further establishes the quality of the data used to develop survey questionnaire (Walker, 1997, [Cross-reference: Hammersley and Atkinson (1983, p. 199)]).

Summarily, the qualitative phase of this research focused on a strategic approach of improving OSC adoption through identifying the existing influencing factors from UKCI professionals, breaking them down into constituent elements, separating them into drivers and barriers and using change management approach and observed constructs from review to categorise the identified factors. The work done here is more of a strategic approach than technical approach. The quantitative part therefore addresses the technical part by statistically estimating the

criticality of the identified factors to wider OSC adoption and proposing technical options to improving OSC adoption. Additionally, it employed ML approach to identify the algorithms with best accuracies that can be used for predicting the factors that favour OSC adoption.

Therefore, at each step of the quantitative data synthesis process and questionnaire development, strategies including conformability, transferability, currency, and such., were applied to improve the trustworthiness of the data synthesized from qualitative analysis.

4.4.7 Quantitative Approach

Construct Development (The Triangulation)

The questionnaire constructs were developed by triangulating the interview analysis outcome with factors identified from the UK-focused SLR 3. The triangulation principally followed the exploratory sequential design as recommended by Plano-Clark et al., (2008) because the topic under investigation is an emerging research area with overlapping ideologies and reports on adoption influencing factors.

To this end, the construct development did not adopt any particular existing frameworks in synthesizing the constructs but allowed the constructs to emerge inductively from the triangulation exercise based on the research aim and objectives as recommended by Creswell & Creswell, (2018). However, existing historical, social and technical frameworks from extant studies (like ADKAR, CBAM, RIBA-PoW, DTI, PESTLE, SWOT) guided the choice of constructs developed as suggested by Crotty, (1998). This is important for an approach that seeks interpretation of knowledge in an emerging study area such as OSC adoption; unlike an explanatory approach that seeks validation on an existing knowledge (Crotty, 2020) [CrossRef:

(Crotty, 1998)]. Moreso, the study, being geographically constrained to the UK, required that the context of OSC adoption factors be understood within the boundaries of the study area before quantitatively measuring the criticality, degree or severity of the factors or issues discovered (Shiyanbola et al., 2021) on the level of adoption.

Amidst other operationalisation and crossover analysis (triangulation) principles considered; an underlying one is the use of domain-specific philosophies as construct-specific philosophy and the emic-etic perspectives (Onwuegbuzie et al., 2010). Other construct validation and development guides used are the Instrument Development and Construct Validation (IDCV) framework developed by Onwuegbuzie et al., (2010), the multitrait-multimethod matrix (MTMM) developed by Campbell & Fiske, (1959). Additionally, the works of Shiyanbola et al., (2021) on exploratory sequential mixed methods design provided a good background for approaching the mixed method triangulation.

The construct development paid attention to content-related validity and construct-related validity, thus addressed convergent and discriminant validities (Campbell & Fiske, 1959; Onwuegbuzie et al., 2010). The constructs design also addressed concurrent and predictive validities to ensure predictive analytics can be carried out with machine learning by measuring OSC adoption percentage of current (or considered) projects and time taken to complete same if OSC was used or if not, including possibility of using the information to predict future adoption. Items on the constructs that are not relevant to the phenomenon of interest (POI), appears too broad and/or is seemingly measuring same criticality as a more relevant one were all dropped. Upon review, the researcher was debriefed on the developed constructs, thus

provided with better understanding and an audit trail of the measuring instrument. The constructs and variables were refined following pre-test feedback. *See Figure 4.3*

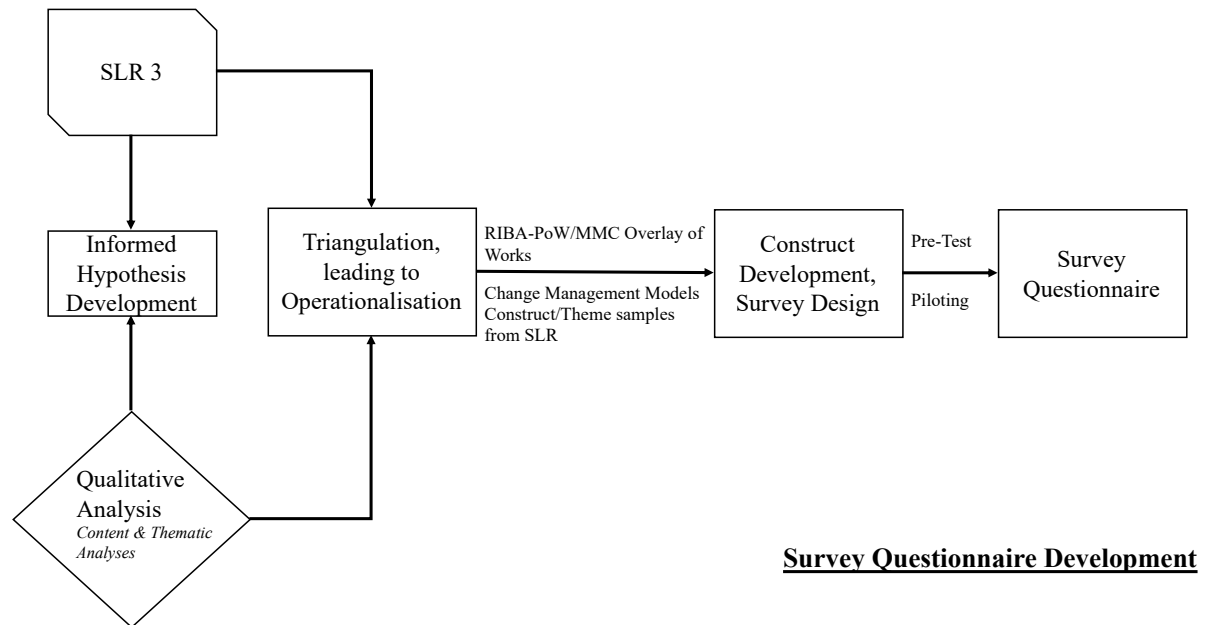


Figure 4.3: Survey Questionnaire Development

Survey Pre-Test

The developed constructs were put together into a questionnaire survey design. The questionnaire was sectionalised and then pre-tested to measure how well it suits its purpose. There was extensive back and forth review with the study's research supervisors on the questionnaire which lasted more than four (4) months. During this period, the survey was pre-tested by a statistician and machine learning expert, an academic (a principal lecturer status), a practicing architect and a fellow PhD researcher (Malmqvist et al., 2019). The selection of pre-testing participants ensured industry and academic views were taken into consideration during questionnaire development. It also ensured proposed analytical measures' viability was given a consideration. The feedback received from my supervisors included the volume of the questions to be asked was much, the further explanations made on the questions should be

concise, the font type and size should be readable at 100% zoom, the questions asked should align with the project aim and the clarity of the dependent variable given that the a predictive analysis would be done.

Survey Questionnaire Development

Survey questionnaire was first drafted and first developed in MS Word and in plain English Language using century gothic font size 9 as suggested by Adams & Cox, (2008). The first questionnaire draft presented was appraised for conformity to statistical analysis and machine learning development by the supervisory team. The draft was also examined for sentence structure, meaning conveyed and clarity as suggested by Addington-Hall et al., (2007).

The questionnaire was designed to measure how much OSC was adopted on the selected projects by a respondent, and not an interrogative finding around OSC or general construction. To this end, a short paragraph describing OSC, the different nomenclatures that describe OSC and the research aim, introduced the research questionnaire to respondents. The questionnaire design ensured informed consent of the participants by adopting and modifying the consent form from SSAH ECDA (*See Appendix 9*) to fit into MS Forms. They were provided with the option of declining, if for any reason(s) they feel uncomfortable answering the questions or withdrawing from participating in the survey questionnaire at any point (Husband, 2020). Bearing in mind the significance of reliability and validity in research, the study used simple and clear, yet professional tenses and terms in asking the questions (Adams & Cox, 2008), aside other measures like triangulation, in-depth review (back-and-forth corrections), pre-test, that have been discussed above.

The first part of the questionnaire provided introductory note to potential respondent about the study, requested for their consent to take the survey and highlighted the survey pre-requisite. The second part measured few non-personal information about the respondents as related to construction practices and the OSC project(s) they have selected for the survey. The third part focused on the construct variables (developed from the triangulation of SLR 3 and interview analysis) criticality measurement using Likert scale. The fourth part allowed for respondent's input in the form of general comment on any other factor(s) or issue(s) bothering around OSC that may have been omitted in the body of the questionnaire. Further, the respondent was asked if they have any other OSC project they would be willing to repeat the survey with before submitting the filled questionnaire. It concluded by thanking the respondent for taking part in the survey and enjoining them to click the submit button to end the survey.

To qualify for attempting to take the survey, a potential respondent must have been involved in or considered using OSC in their projects. The questionnaire thus focused on drawing facts from OSC projects executed or considered rather than perceptions or opinions which has long permeated the numerous research approaches to OSC (Kordi et al., 2022; Willits et al., 2016). The respondent's inclusion and exclusion measures, such as having OSC project experience within the UKCI, helped reduce biases to the barest minimum and increase validity as it unlikely for two individuals on the same project to report OSC usage from opposite ends of the scale even though they may have differing opinions on OSC usage level on the project. To this end, the scale did not reflect the 'neither-nor', 'indifferent' or 'indecision' category. Since the questionnaire aimed to gather reasonably large data size for the ML approach, a less burdening scale, such as 5-point Likert scale was adopted (Manisha Khandelwal, 2021).

The variable criticality being measured were scaled on a five-point Likert scale. Likert scale has been employed by numerous quantitative research works because it has been observed to provide good reliability result, reduce ambiguity and improved speed and quality of response (Cummins, 2003; Kordi et al., 2022; Willits et al., 2016). Likert scale provides a range of view beyond what a yes or no survey does, thus affording a study a better representation/measurement on opinions/facts about an issue.

Five-point Likert scale, when compared to 7 and 9-points scales, is less frustrating to respondents in selecting their choice answer for a question, thus increases response rate (Gliem & Gliem, 2003). It affords nuanced, actionable, straight-forward and relevant feedbacks (JotForm, 2023). It is widely used in various research fields such as social sciences, medical fields, engineering, biological science, statistic to mention a few (Voxco, 2022). It allows for lower error margin and fits mobile screen better (Work Tango, 2023). While a school of thought argues that larger scale Likert categories offer better options to select from and provides a more stable Cronbach's Alpha value and greater validity due to increased response variability (Joshi et al., 2015), they however increase the burden and fatigue of respondents and may reduce response rate and quality (Revilla et al., 2014). Other school of thoughts argued that reliability coefficients obtained does not significantly increase with increased scale options but stabilizes on a 5-point scale and continues with same reliability value with scales like 7 and 9 (Gliem & Gliem, 2003; Willits et al., 2016). More importantly, a 5-point Likert scale provides good data distribution and is well adapted to various statistical measures such as t-test, Anova test, chi-square test. (Gliem & Gliem, 2003; Willits et al., 2016), [Cross ref: Jacoby and Matell 1971; Matell and Jacoby 1971; Schutz and Rucker 1975; Green and Rao 1970; Preston and Colman 2000; Lissitz and Green 1975].

The font used, Segoe UI, size 10.5, the default setting of Microsoft Forms of Office 365. No graphical setting was included in the questionnaire design. The questionnaire was accompanied with a brief introductory opening which highlighted the motivation and aim of the research. Though the questionnaire has one hundred and three (103) questions in all (sixteen (16) demographic variables, one (1) dependent variable and eighty-six (86) independent variables). The questions were divided into sections in line with the aggregation of the systematic literature review and interview analysis to make sure answering the questions do not bore the respondents. The independent variable questions were on Likert scale which make answering them easy, simple, clear and straightforward (Qualtrics, 2023; Willits et al., 2016). To ensure anonymity, the questionnaire never requested any personal detail of the respondents other than professional and project information as deemed fit for the research (Saunders et al., 2015). The questionnaire asked questions only relevant to each construct, clearly communicate what is being asked and asked information on the project the respondents has done and/or has information on. The respondents were advised to note the selected project of interest and its relevant information by the side and possibly the project file (where available), before commencing the questionnaire responses. This approach is in tandem with the works of Meadows, (2003), [Cross Ref: Miller (1984), (Frey 1989), Sudman and Bradburn, (1982)].

The questionnaire was administered electronically and the design allowed for immediate response notification once a respondent completes one. This helped track the response progress on the questionnaire and to know when responses are within the range of targeted number of responses. While in most research, a respondent can fill only one survey form, this study, being project based, allows a respondent to take the survey more than once. This is to say a respondent

who has been involved in or considered five different OSC projects can take the survey one to five times using any of the projects.

Overall, the questionnaire considered the research focus, the ease of response and the intended analysis for the research.

Sampling

Sampling provides the basis for inferential statistics when the entire population cannot be sampled (Fowler Jr, 2013). The selected sample adequately represented the characteristics of the population being examined to ensure findings are generalisable (Creswell & Creswell, 2018). A sampling frame can be informed by time and budget constraints or if impractical to get everyone needed for the research (Bryman, 2016). Therefore, in research, a sampling technique is usually a function of how best it is to get the high-quality relevant data to address the research objectives (Etikan, 2016). For the quantitative phase of this research, a combination of Purposive sampling and Snowballing were used as recommended by Palinkas et al., (2015) and Saunders et al., (2009). Purposive technique was employed because the questionnaire is targeted at UKCI stakeholders with OSC project experience, and snowballing because of the slow response rate, owing to difficulties in getting CI stakeholders.

Sample size.

Sample size is a subset of the population of a study. It provides adequate representation that supplies enough information to ensure a generalisable conclusion for the study. In this research, the population is the UK construction industry stakeholders, especially those with knowledge or experience in OSC. The study sample size was determined a-priori (Serdar et al., 2021) as it proposed gathering 500 responses because it intended to use Machine Learning in achieving

one of its objectives, though a lesser sample size emerged from calculation (~380). To achieve the 500 responses and ensure the targeted sample size satisfies the minimum required for ML application, the population size of the construction industry and OSC construction workers were estimated using data from the United Kingdom Office of National Statistics (UK-ONS). Additionally, the margin of error (ME), which expresses the random sampling error in a survey study and the result, and achieving significant level and confidence interval at 95% probability were considered (Kotronoulas et al., 2023; Serdar et al., 2021). Other factors considered were cost and time effectiveness, the unit of analysis and observation, analysis type, selection of analytical approach and coding programme (e.g. using Structural Equation Modelling or Machine Learning Models), the orientation of the research student's supervisor or examiner, budget, time, resources and other constraints like force majeure, anxiety, stress (Memon et al., 2020).

Sampling frame

In addressing the required sample size, the UKCI workforce and the number of OSC projects were evaluated. While UKCI workforce record exist, no documented OSC project data exists. Since getting OSC project information now solely relies on UKCI stakeholders, it became necessary to have a knowledge of how much stakeholders can help achieve the required number of projects in line with the study's unit of analysis and observation.

The Office of National Statistics, UK, as at 5 December, 2023 reported that there are over 1.4 million construction workers in the UK (ONS, 2023). There is however no form of report on OSC projects, nor the number of workforces related to OSC.

A study by the Construction Industry Technical Board (CITB, 2019) reported the 2017-2018 UK MMC workforce to be 493,000, with a required 195,000 workforce needed to keep this arm of the construction industry afloat by mid-2020s if the target of approximately 300,000 homes would be provided annually. Though there is no current update on the present MMC workforce available for the year 2023/2024 but following the 25% OSC/MMC usage project by the UK government, the CITB report, using different scenarios, estimated 317,000-320,000 MMC workforce for the UK MMC/OSC workforce by 2025-26. Thus, a rough estimate of 750,000-800,000 population was adopted for this study. (CITB, 2024).

The relationship that exist between the calculated UKCI stakeholder population and the sample required (number of OSC projects) is that not much people possess OSC knowledge enough to attend to the study survey, therefore, reaching more stakeholders is a good way to increasing the chances of getting adequate number of projects samples to satisfy the studies unit of observation and analysis.

Although scientists and researchers have recognised the importance of statistical analysis sample size and have widely adopted several rules of thumb (such as minimum threshold or power analysis) to calculate sample size, it remains unclear which one to adopt for which study and what sample size can be considered large enough for a study (Memon et al., 2020). Scholars (Hair et al., 2013; Krejcie & Morgan, 1970; Memon et al., 2020) have equally admitted and reported the lack of adequate understanding of statistical knowledge required for determining sufficient sample size for their studies owing to numerous approaches necessary for specific studies. This study, therefore, borrowed leaves from the related extant studies noted and stats expert recommendations in determining the required adequate sample size.

While a large sample size has been noted to provide researchers with great analytical powers and enhances the ability to detect small effects, it also creates problems of interpretation for statistical significance, especially when p-values become significant for trivial effects (Lin et al., 2013). On the other hand, small and moderate sample sizes provide good interpretation for statistical significance, but the statistical significance alone is not sufficient to approve a sample size (Serdar et al., 2021). Similarly, the correlation coefficient and p-values alone are insufficient to justify adequate sample size as these do not account for effect size, variability or study power (Sullivan & Feinn, 2012). As noted above, critical factors, such as effect size, power, study efficiency, confidence interval, were considered in line with this study's aim and objectives. Therefore, considering these factors across the board and following the advice of the research supervisory team, internal examiners for the study initial and progression assessments, industry and academic domain knowledge (Daget & Zhang, 2019), a project sample size above 300 is deemed sufficient for both statistical analysis and ML model development. For example, using Cochran's formula,

$$n_0 = \frac{Z^2 \cdot p \cdot (1 - p)}{e^2}$$

Where: n_0 = sample size

Z = Z-value (1.96 for 95% confidence interval)

p = estimated proportion of the population (using 0.5 for maximum variability (conventionally adopted estimate))

e = margin of error (assume 0.05)

$$n_0 = \frac{(1.96)^2 \cdot 0.5 \cdot (1 - 0.5)}{(0.05)^2}$$

$$= 384.16$$

While three hundred and eighty-four (384) sample emerged from calculation, considering time and response rate, and a margin error of 5%, a sample size of minimum 300 was considered adequate to progress with. This choice is buttressed by the works of Balogun et al., (2024), Egwim et al., (2023) and Wusu et al., (2022) who used between 280 and 320 sample sizes. Three hundred and thirty-seven (337) responses were eventually received for quantitative analysis.

Piloting

While the pre-test paid much attention to the questionnaire development, wordings and understanding of the survey design, the piloting focused on how the respondents feel about the questionnaire, interpreted it and related with it while answering it. Both pre-testing and piloting are used to identify likely pitfalls that may compromise the reliability and validity of the questionnaire and correct them before they are administered (Adams & Cox, 2008).

Seven people were purposely selected for piloting the questionnaire- two (2) academics of principal lecturer status, both of whom have construction background and have worked on OSC in the past, an architect, a building engineer, a realtor and two (2) potential end-users of OSC buildings. All the pilots have some form of experience on OSC. The piloting took 2 weeks due to the unavailability of the pilot members. The responses received from the pilots indicated the questionnaire satisfied a valid questionnaire criteria, content and construct (Ray et al., 2016). Validity measure how well the question measures what it is intended to measure while reliability examines how well a group of answers appraise a particular concept/construct in the questionnaire (Abbas, 2023; Bhatnagar et al., 2014; Bowden et al., 2002). Also, validity

measures the accuracy and truthfulness of the research findings while reliability ensures the consistency and reproducibility of the research findings across different occasions, researchers and instruments (McLeod, 2023). To ensure reliability and validity criteria are achieved, a mix of industry expert, academics and potential OSC users were invited for piloting.

Cognitive discussion was held with the pilots (Regmi et al., 2016) to appraise their responses on the questionnaire before effecting their comments. Most pilots feedback affirmed that the questionnaire is well developed, the questions are well framed and quite explicit and thus good for its intended purpose. Some of the comments received are the questionnaire is basically categorical and may not be good enough for some type of analysis like mathematical modelling. Other comments are to make social sustainability and change management factors more pronounced in the questionnaire. One of the pilots advised that another survey platform should be used to improve the presentation of the Likert scale questions subject to school's approval. This questionnaire was tried with JISC Online survey but was dropped because the improvement being carried on JISC Online survey during the period was compromising the reliability of the survey response. Owing to brevity of time, other approved online surveys were not tried. There was a back-and-forth conversation with the pilots based on their comments. The response time recorded during piloting was approximately 56 minutes while the repeated piloting took less than about 28 mins.

The repeated cycle of piloting further ensured reliability (Meadows, 2003). Feedback from the pre-test and pilot ensured the questions, though not in all cases, were kept short, simple and well-defined, with additional information only where necessary since the questionnaire is a self-completing exercise. Respondents are encouraged to keep of a note of the selected project

to be discussed by their sides before commencing the questionnaire response in order to recollect and provide the most accurate information on the project, in order to save their time. Those answering from mobile device were also encouraged to turn their phone to landscape position to help them capture the entire Likert-scale options.

Ethics approval

The questionnaire was submitted to ethics committee as a follow-up on the qualitative approval obtained. Having met the quantitative questionnaire requirements, approval was obtained from University of Hertfordshire Social Sciences, Arts and Humanities Ethics Committee with Delegated Authority (SSAH ECDA) having same ethics number BUS/PGR/UH/05327.

Questionnaire Administration

The questionnaire was administered online in line with ethical approval. Online questionnaire is an emerging data collection approach that much research works in academics and industry are fast embracing (Baltar & Brunet, 2012; Evans & Mathur, 2018) because a sizeable number of the world population are now connected digitally (Kemp, 2024). A 2023 account has it that the UK has about 63-66 million internet users (Broadbank UK, 2022; Petrosyan & Statista, 2023) from over 67 million UK population, accounting for over 95% users, most of who are full time workers (Simon, 2023). Another study shows that 74% of UK working class (54% full time worker, 13% part-time worker and 7% freelancers or self-employed) being active internet users with only 5% retirees as internet users (Statista, 2023). Since construction industry employs over one-third of UK population (CITB, 2024; Nadim & Goulding, 2009; Perera et al., 2022), it would suffice to say most construction industry workers are active internet users and are usually online (Simon, 2023). Moreso, online survey collects large

amount of data and report same faster. Online survey is economical to use, easier to collate, connect with other software, easy to analyse, prevent data loss (due to human handling in paper survey) and provides higher degree of anonymity for very sensitive research studies (Regmi et al., 2016). Also, considering the use of technological gadgets and systems being introduced into the constructions industry in recent times and especially the introduction of technological advancement in MMC, it can be assumed that most workers within the industry today have some knowledge about use of online medium, at least as they have used for work registration and clocking-in.

The online means used were the link and QRCode generated from MS Forms. MS Forms is preferred from the approved list of online questionnaires tools/platforms by the university because it is user friendly and has higher security aside being viewable on both computer and mobile interfaces. Moreso, the branching and nodal connections of interdependent questions appears to link better than others. Also, it does not require every time access code to log into. The interfaces on both computer and mobile are user friendly though the mobile has a shortcoming of too thin width for Likert questions.

Some of the strategies employed in the questionnaire administration included use of professional social media platforms of various offsite bodies and associations in the UK like LinkedIn (engaging with the hashtags of offsite groups social media handles (such as #kier, #offsiteexpo, #buildoffsite, #offsite alliance, #mbi, #offsitebuildings, #moderndmethodesign, #mmc, #portablebuildings, #mobilehomeinvesting, #portalcabins, among others) and contact email addresses found on their websites. Snowballing through interview respondents, and

allied professional construction platforms, and such. were also employed. This was to spread the reach of data collection as far as possible.

This research does not claim to have got the best respondents within the UK construction industry to fill the questionnaire. However, it ensured some of the best hands-on general construction and particularly OSC project attended to the survey from the way the mandatory section leading to filling the questionnaire was designed. Mandatory question on respondent's OSC project knowledge and experience were basis to take the survey after consent (Kordi et al., 2022). Though questionnaires are not usually designed for a single respondent to fill multiple times (Regmi et al., 2016), but since this questionnaire is project based and not individual based, respondents are encouraged to fill the questionnaire with as many OSC projects they have considered or executed choosing only one project in each case of attempting the questionnaire.

The questionnaire administration maintained ethics guidelines and approval and also ensured confidentiality and ethical data management.

Questionnaire Responses

The questionnaire garnered a total of 337 responses. 312 of the responses were valid and useful for analysis while 25 were not useful for analysis but they useful for drawing some sort of inference for research (*See quantitative analysis on chapter 6*). The total spread of the questionnaire distribution could not be fully tracked because of snowballing and the use of different social media channels such as OSC/MMC groups on LinkedIn, therefore, the response rate could not be calculated. However, using the number of responses gathered against an estimated target response, the response proportion was approximately 67.4% (going by the 500

response target) while the average response time was 58.56 minutes. The quantitative data gathered was analysed for critical factors influencing OSC adoption in the UK using Machine Learning approach (*See Chapter 7*). The critical factors identified were used to model predictive algorithms for OSC adoption in the UK.

Chapter Summary

The chapter discussed the methodology underlying this study and the methods used in synthesizing and gathering data. The study science was pragmatism, and it used a mixed method approach. Pragmatism is not fixated on any one reality or philosophy. Rather, it liberally draws from the mixed method approach assumptions engaged in the research (Creswell & Creswell, 2018). Following factors deduced from literature reviews, the study developed semi-structured interviews for inducing OSC knowledge from UKCI professionals. The interview analysis outcome, together with finding from SLR 3 were used to develop a survey questionnaire which gathered quantitative data for further analysis

CHAPTER FIVE

5.0 ESTABLISHING UK-SPECIFIC OSC INFLUENCING FACTORS THROUGH QUALITATIVE APPROACH

Chapter Overview

This qualitative approach sets out to unravel, identify and establish OSC adoption influencing factors responsible for the low adoption of OSC within the UK construction industry from the numerous reported ones globally in line with the second objective of this research. To achieve this, interviews were conducted with UKCI professionals with knowledge about OSC. The interview data were transcribed and analysed using content and thematic analysis. The results were triangulated with the UK-focused SLR on OSC adoption and operationalised into survey questionnaire for gathering quantitative data.

5.1 Chapter Introduction

Scholars opine that where there are not enough literature from which to draw in-depth knowledge on a subject under research, or where the subject being research is an emerging topic area, approaching the research qualitatively will provide rich information beyond what quantitative approach would do. Since OSC is a rejuvenated concept within the construction industry and current array of literature do not clearly articulate the critical factors influencing OSC adoption, especially in the UK, it became imperative to approach the research qualitatively.

In achieving the objective of this chapter which is to establish the most relevant OSC influencing factors to UKCI from extant OSC studies, a literature review was first conducted to establish existing varying global OSC adoption influencing factors level that represent international context (Moher et al., 2007; Schlosser, 2007). Secondly, factors deduced from the review were used to develop interview questions for UKCI professionals. Semi-structured oral interview was conducted via zoom and MS Teams with industry professionals within the UK construction industry to establish the relevance of existing factors reported by academic scholars to UKCI (Bloomberg & Volpe, 2015; Nickoson & Sheridan, 2012).

5.2 Interview Sample Frame

The qualitative sample frame was purposely drawn (Palinkas et al., 2015; Saunders et al., 2009) from the population of UKCI professionals with experience on OSC construction methodology to induce UK-specific OSC knowledge (Kirsch & Sullivan, 1992). These professionals are believed to possess required knowledge on both general and modern methods of construction practices and can provide rich contextual information on OSC adoption in the UK (Drescher & Edwards, 2019; Palinkas et al., 2015). They were sought through industry reports, professional bodies social media groups and platforms, construction events, snowballing, and such. See *Section 4.4.3* for details.

5.3 Interviewees' Profile

The demography of the respondents shows that the set of interviewees are well experienced in the practice of construction works as well as Offsite constructions. Wuni & Shen, (2020) noted on the importance of using well experienced construction experts for gathering construction related information owing to lack of central database. The minimum years of experience

observed from the interview demography is five (5) years while the maximum is forty-five (45) years. With a respondent not stating the numbers of years of experience (but noted a long period of experience), the average years of experience in the construction industry was 22.7 years. The minimum number of years of experience on OSC was four (4) years while the maximum number of years of experience on OSC was thirty (30) years. With only seven (7) of the twelve (12) interviewees being able to put a number to their years of experience on OSC, the average years of experience on OSC is thirteen (13) years. All the interviewees were still active in practice as at when interviewed.

Considering the most recent developments around OSC has occurred in the last ten years, the demography of the interview participants shows a degree of wealth of experience both in the general construction and offsite construction industries as being adequate for the research. Moreso, this research improved on some of the extant literature who have used participants with lower years of experience. For instance, Gbadamosi et al., (2020) used minimum of 2 years general construction expert experience, while Yu et al., (2019) used 5 years construction industry experience. Wuni & Shen, (2020) interviewed professionals with less than 6 years of experience, while Goulding & Rahimian, (2019) did not report on the industry experience level of its interviewees. **Figure 5.1** shows the comparison between the respondents' years of experience in general constructions and offsite constructions.

NB: Where the number of years is void in the graph, it is because the interviewer could not pin a number of years to the experience. The adverb 'numerous, many and well experienced' was used to qualify the years of experience and this cannot be translated into figures. But looking at their experiences, it was suggestive they have around 10 years OSC in the UK.



Figure 5.1: Industry experience of interview respondents

While majority of interviewees have architecture background, the said architects have over the years and practice further developed their skills and experience in areas such project and construction management, engaged in construction businesses on various projects that cut across major areas of practise in construction such as healthcare, education, leisure, sports, and the likes. Having much architect in CEM research is not unusual. For instance, Jaillon & Poon, (2010) in a research conducted on design issues relating to OSC has most of its respondents being architects (28%).

Almost all the afore-stated construction industry professionals were covered by the interviewees demography aside MEP engineers. This is because the numbers of MEP engineers within the general construction industry is appreciably low (Hanna et al., 2016). It should however be noted that a few MEP engineers were contacted specifically for this research, but

they made up part of the respondents that agreed to take the interview but did not show up eventually.

The type and volume of projects the respondents have worked on is reported in *Table 5.1*. This further demonstrated the wealth of industry experience, justifying why they were considered for this research.

Experience			(Overall)		experience
R1	Architectural Technology and House building	Developing learning materials for Sustainability School	About 45 years	Yes	Over 30 years DfMA designs
R2	Architecture	Project delivery leads to higher education, primary health care, transportation infrastructure and residential building for an offsite body.	28 years	Yes	Much DfMA designs, DfMA over build offsite.
R3	Furniture maker, construction technologist and manager, researcher with PhD in Construction Skills	Research Education and discipline/skill specialist, Research Lead in Building Innovation with an interest in construction industry skills	Over 10 years in the construction industry almost 4 years in building research	From an educational/ research perspective and policy development	4 years
R4	Architecture	Consultant	Over 30 years	Yes	Well experienced
R5	Construction Management	Construction manager, Lecturer	Over 10 years in the industry, 6+ years in the academics	Yes Member of offsite construction community (Offsite Alliance)	> 5 years improving construction processes
R6	Architectural Technologist lead project management architect, OSC Consultant	Technical solution provider for OSC	Over 40 years of construction industry experience	Yes, Specialize in timber, steel, and concrete. Collaborated with an offsite home provider.	21 years in OSC
R7	Architecture	Architectural Office.	25 years	Yes,	Well experienced
R8	Architecture	Architectural technologist, computational design coordinator of the manufacturers	5 years	Yes	4 years
R9	General practise, Chartered Surveyor	Alliance for OSC products knowledge sharing group	25 years	Marketing	Well experienced
R10	Architecture	Technical manager at a timber engineering company, chair of an offsite group (8 OSC groups) Process improvement (strategic development position), works with the supply chain team	Well experienced	Worked with a company building fully volumetric OSC	Well experienced

	Manager Site Agent	manufacturing company			
R12	Senior Lecturer (Construction Management)	Worked at a leading offsite home developer. Former Operation Manager, Geo-Technique Officer	Over 10 years		Over 7 years

5.4 Interview Data Synthesis

The interview protocol had two major questions relating to OSC and emerging modern construction technologies (*See Appendix 4*). Both questions were open-ended (broad and general) questions so that interviewees can construct the meaning of a situation, enabling an interaction that gave room for further probing and discussion on OSC adoption issues raised. Creswell & Creswell, (2018) underscores the approach of open-ended questions as being the better approach to interviewing in a social constructivism (interpretivism) setting. A set of probing questions was formulated from the SLRs (not included in the administered interview call- *see appendix 4*) to further probe grey areas and emerging topics around OSC. The interview protocol was designed in MS Word and administered through email.

The interview call was first piloted by three (3) people- an academic who ensured it satisfied academic requirements, an industry professional who ensured it covered emerging topics within the industry and a potential end-user who gave an honest opinion from users' perspective (Wusu et al., 2022). The pilot observations on the interview protocol (open-ended questions and further probing questions in a semi-structured format) were noted and revised accordingly. The interview protocol was submitted to ethics for approval. This study got approved by the University of Hertfordshire Social Sciences, Arts and Humanities Ethics Committee with Delegated Authority (SSAH ECDA) with the Protocol Number BUS/PGR/UH/05327.

5.5 Interview Data Analysis

Analysing the qualitative data took two routes- content and thematic analysis. The content analysis, identifying and counting the number of factor mentions, provided a manifest surface meaning of texts, through the counts (*See section 5.5.1*), while thematic analysis afforded

latent, implicit, underlying, contextual meaning of texts of the identified mentioned factors (*See section 5.5.3*) (van Esch & Esch, 2013). Both approaches fulfilled the six (6) steps of qualitative data analysis as laid out by (Clarke & Braun, 2013; Ulster University, 2024). The content analysis focused on the identifying key concepts (factors) and the frequency of mention of the factors, thus assigning suggestive significance to such factors based on their frequency of mention and the criticality of factors aimed at in this study. The thematic analysis focused on the lines of thoughts, arguments and logical reasoning along the line of the factors mentioned by identifying patterns and meanings which are necessary for drawing inferences, discussions and conclusions for the study. The analyses also observed related constituting issues to the identified factors.

The interview analysis also noted the factors the interviewees referred to as major or minor from the discourse. Some interviewees highlighted these factors as internal, external or emerging factors aligning with the ‘inter’ and ‘intra’ idea conceptualised in *Chapter 3*. The analysis also noted the industry reports referenced as basis for their positions during the interview session. *See Table 5.2* under content analysis. *Figure 5.2* below describes the analysis of qualitative approach.

Table 5.2: Factor Count and Industry Number Report identified by respondents.

Respondents	Total No of factors identified by respondents	Major Factors by interviewee respondents	Minor factors by respondents	Number of industry reports referred to by respondents
R1	20	12	5	4
R2	14	2	4	3
R3	10	3	0	3
R4	10	0	0	0
R5	8	0	0	4
R6	17	4	2	1
R7	12	6	0	0

R8	13	7	0	0
R9	3	3	0	1
R10	11	4	2	0
R11	10	2	1	0
R12	8	4	0	0
Total	136	47	14	16

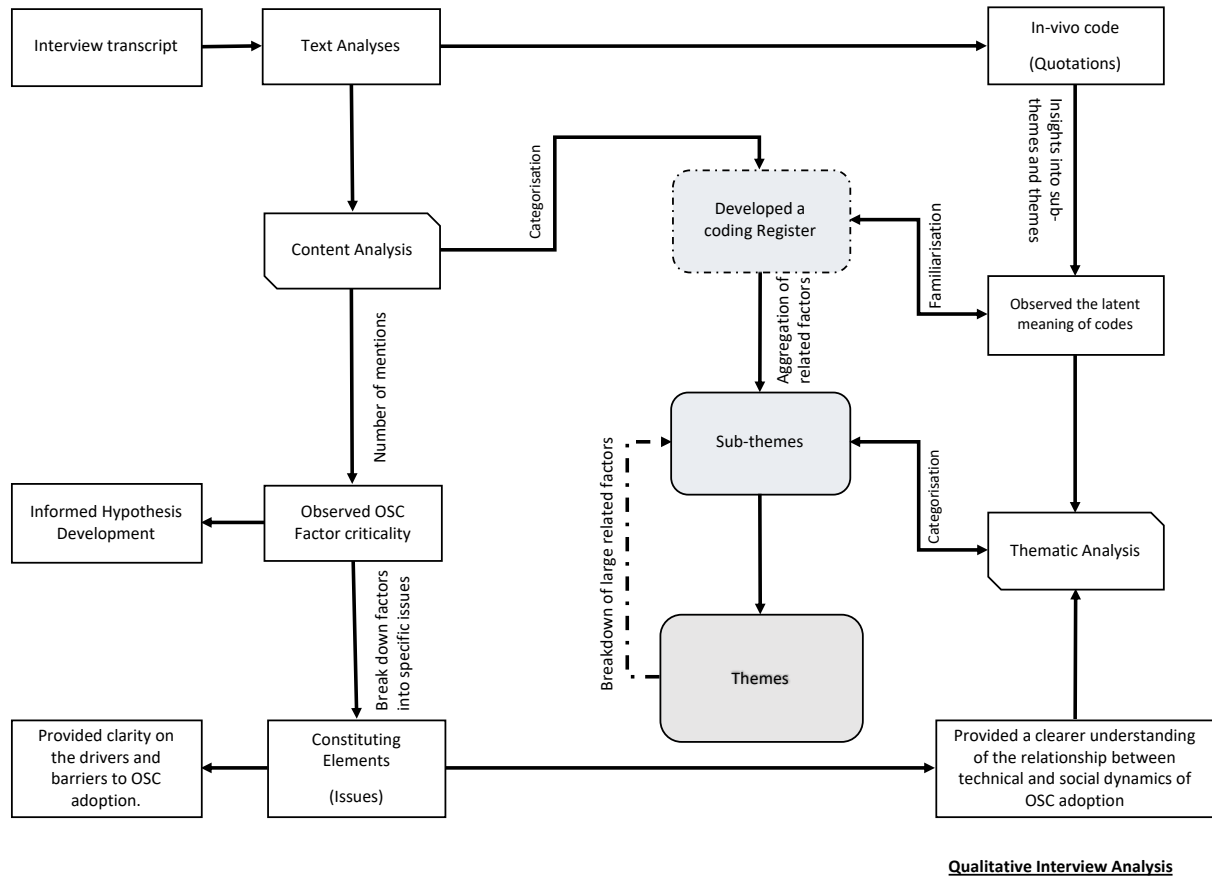


Figure 5.2: Qualitative Interview Analysis

5.5.1 Content Analysis

The interview transcripts were appraised for OSC influencing factors and issues raised based on their frequency of mentions. The content analysis was used to identify and count the mentioned factors influencing OSC adoption based on the frameworks, reported groupings and

classification guidelines observed from the reviewed literature. The counts provided a suggestive importance of the factors. The content analysis flow is given below.

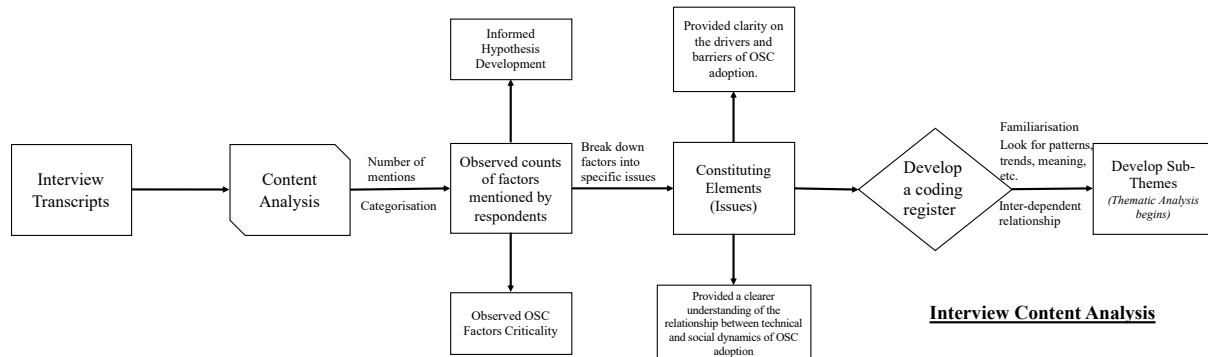


Figure 5.3: Interview Content Analysis

A total of one hundred and thirty-six (136) factors were reported by the interviewees. Forty-seven (47) were major factors and fourteen (14) were minor factors respectively by the 12 interviewees. It was also observed that 6 of the 12 respondents consistently referred to industry and non-academic articles as resource materials for the basis of their positions on the discussions. 12 distinct non-academic articles were noted from 16 mentions (*See Table 5.2*). Upon further examination of the factors using an open-coding approach, highly related factors were compressed together, and the factors were trimmed to eighty-three. After review with the research supervisors and comments from progression examiners, some factors were merged and the number trimmed to seventy-nine (79). *Tables 5.2 and 5.3* below present the total number of factors extracted from the sessions by interviewees and by factors identified. On further examining, analysing and clustering the number of factors, a coding register used for commencing thematic analysis was developed- that is, *Table 5.3*, (*See Appendix 7 for details*).

Table 5.3: Summary of interview content analysis (Coding Register)

S/No	Clusters (Theme)	Total Respondents' Number of Mention	Weight Respondents' Number Mentions (%)	of Factor Count (Sub-Theme)	Weight of Factor Counts (%)
1	Supply Chain and Logistics	19	13.97	12	15.19
2	Time saving	15	11.03	4	5.06
3	Productivity	14	10.29	13	16.46
4	Perception and Attitude	13	9.56	5	6.33
5	OSC Buildability	11	8.09	9	11.39
6	Quality Performance	10	7.35	4	5.06
7	Construction Industry Enterprise	10	7.35	5	6.33
8	Cost	9	6.62	5	6.33
9	Environmental Sustainability	7	5.15	3	3.80
10	Awareness	6	4.41	4	5.06
11	Government Policy and Interventions	6	4.41	4	5.06
12	OSC Knowledge	6	4.41	5	6.33
13	Health and Safety	5	3.68	2	2.53
14	Stakeholders' Influence	5	3.68	4	5.06
		136	100	79	100

NB: See Appendix 5 for detailed factors identified for content analysis.

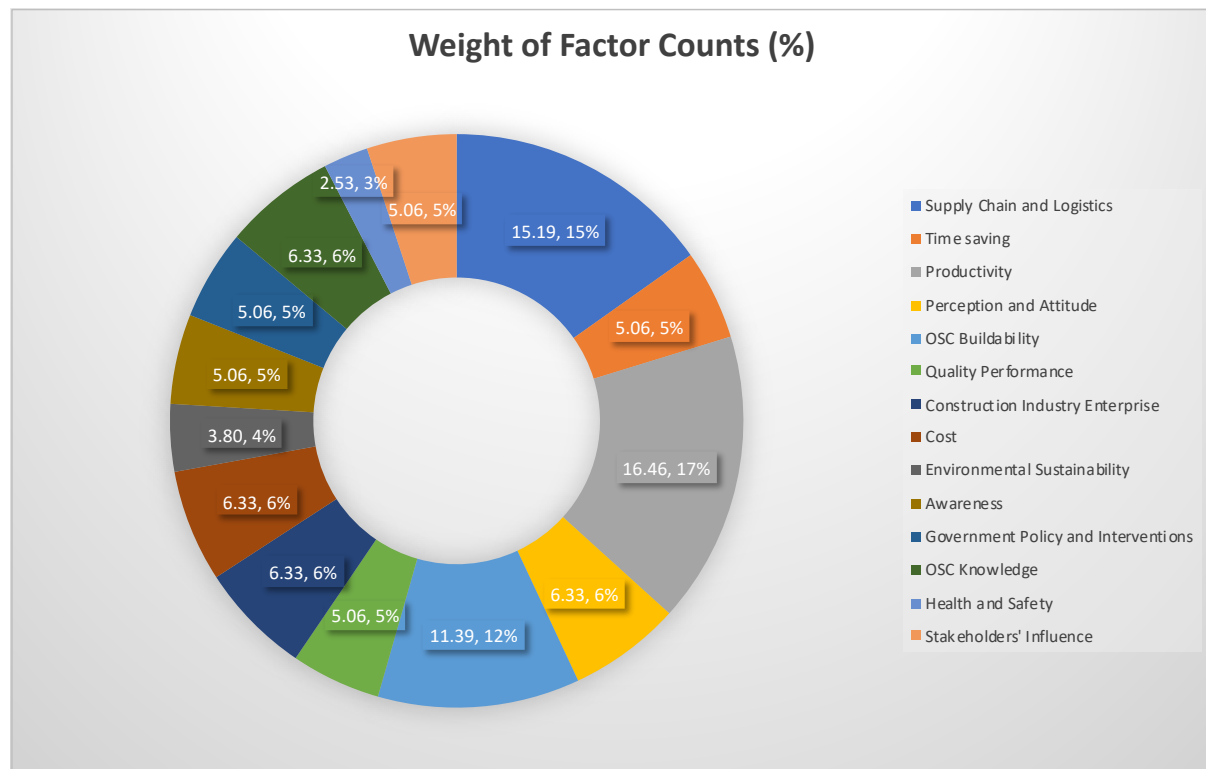


Figure 5.4: Weight of factors identified from interview analysis.

On clustering the seventy-nine (79) factors, twenty-five (25) clusters bordering around wider adoption of OSC were identified. This clusters, when reviewed under a set of ‘third’ eyes, were compressed into fourteen (14). By weight, the most conspicuous clusters were Supply Chain Management (19 factors), Time Saving (15 factors), Productivity (14 factors), Perception (13 factors), OSC Buildability (11 factors), Improved Quality Performance (10 factors) and Construction Industry Enterprise (10 factors). All the conspicuous clusters have weight over 7% of the total weight. Two more factors, Cost and Improved Environmental Performance, showed weights below 7% and above 5% respectively while 5 clusters weighed between 5%-3%. No cluster weighed below 3.5%, which indicated all the clusters have appreciable influencing impacts that attention should be paid to.

The clusters with high counts are suggestive of high importance and are therefore combined with content analysis from findings from SLR 1 to formulate hypothetical statements to be tested. The fourteen factors formed the coding register- a closed coding approach for thematic analysis and provided the springboard for commencing same.

5.6.1 Notion of Clusters

Qualitative research generates too many factors as outcome (van Esch & Esch, 2013). The seventy-nine (79) factors identified were deemed numerous, with some of the factors not fitting under significant clusters. Nadim and Goulding, (2010) recommended that care should be given on how data is collected and how research outcome should be categorised based on research focus. Since this study employed the pragmatic philosophical approach which emphasises using the best method to achieve the required result and following the core objective of this research which is to establish the critical influencing factors of OSC within the UK construction industry, this study employed a combination of categorisation techniques observed in the reviews.

Therefore, in clustering the identified factors, a few established categorisations were examined from extant literature. The most suiting and applicable broad selection ranges from the reviews, in addition to RIBA-PoW, were adopted from the existing categories as best fitting to the objectives of this research. This follows examples from extant studies. For instance, Chen et al., (2010) classified thirty-three (33) sustainable performance criteria under three (3) broad heading of economic, social and environmental factors. Balogun et al., (2022) approached classifying the factors influencing deconstruction using the TELOSS (Technical, Economic, Legal, Operational, Schedule and Social) framework. Egwim et al., (2022) adopted the fishbone (Ishikawa diagram) to classify delay factor from fifty (50) articles into nine (9)

relational categories. Hamzeh et al., (2017) used three (3) level decision criteria to categorise fifty (50) factors determining the values of precast construction. Hamzeh et al., (2017) conclusively classified his research outcome on modular concrete construction differing perspectives in Lebanon as technical, aesthetic, logistical, organizational, and cultural factors (as key barriers) and cost, time, sustainability, and flexibility factors (as key drivers) influencing the choice of building prefabrication construction methodologies. Goulding et al., (2014) classified the influencing factors of OSC under three main headings- people, process and technology. Razkenari et al., (2020) viewed the factors accounting for the disruption caused by one of the five breakthrough areas emerging within the construction industry under the lens of potential benefits of OSC, the OSC process and the OSC market.

Additionally, and to complement SLR 3, the clusters of factors was examined using the RIBA DfMA overlay of works by the UK modular construction industry in addition to applicable change management theories and frameworks observed from the reviews. This approach further guided the triangulation and operationalisation of the interview findings into constructs that informed the questionnaire development used for measuring the impact of these identified factors.

5.5.3 Thematic Analysis

Data Familiarisation

The analysis started by watching the video recordings attentively and repeatedly to familiarise with the interview transcript contents and issues discussed. Upon auto-transcribing the interview recordings, the transcriptions were edited several times. Cleaning of errors and corrections of tenses were done. The texts were analysed for OSC influencing factors raised

during the interview sections after reviewing and refining transcriptions for readability. The factors were examined for the degree of their influence on wider adoption of OSC within the UK construction industry using content analysis and thematic analysis.

Theming Phase (Generating Initial Themes)

This phase provided comprehensive understanding into the content and context of the recordings. Further, the theming process, building up on the coding register, observed the tone, talking pace, gestures, exclamations and other non-verbal communication cues to aid the interpretation of the codes and development of the themes. The codes captured particular ideas, patterns, trends, topics and arguments discussed during the interview sessions.

To ascertain the validity of the extracted codes in relation to this study and the robustness of the qualitative analysis results (Wang & Sinha, 2021a), the interview transcriptions were subjected to Syntax Analysis, Entity Analysis, Sentiment Analysis, Entity Sentiment Analysis and Subjectivity Analysis using manual method. Where a researcher deals with large volume of unstructured textual data such as interviews, focus group meeting and/or validation of transcripts, Liu, (2012) suggested using text analysis helps identify patterns, emotional tone or relationships across respondents narratives. This use of text analytics has also become increasingly relevant in qualitative studies (Cambria et al., 2013).

In analysing the interview, a table of questions asked versus respondents was created. As the recordings were evaluated vis-à-vis the transcriptions, the table was populated until all issues detailed in the interview were covered. Upon completing the interview analysis, the study progressed to categorise the factors identified by categorising related factors.

Over five hundred and twenty-seven (527) general in-vivo codes (quotations) were generated from the interview analysis aside those belonging to major, minor and emerging issues on OSC (See content analysis Table, *Appendix 7*).

Creating and Reviewing the Themes

This phase of the qualitative analysis combined creating themes and reviewing themes identified. In this phase, the initial themes were further developed into common ideas and categories (which this study terms ‘sub-themes’) across the interview transcripts and in consonance with categorisation types observed from literature reviews and coding register (Agyekum et al., 2019; Bendi, 2020a; Wuni et al., 2019). In developing the themes and analysing the interview outcomes, the entire coding process was refined a couple of times after reviews by the supervision team and some qualitative research experts’ comments. Some themes were separated, re-ordered, and re-distributed while others were discarded because they do not align with the research focus.

Define Themes

Since there is no specific adopted framework of rationalising theme classification for the identified influencing OSC factors in line with the recommendation of Creswell & Creswell, (2018) for mixed method approach, this study relied heavily on RIBA-PoW/MMC Overlay PoW and a few change models mentioned earlier for guidance on theme classification in addition to the observed applicable frameworks from the SLRs and the observed ‘importance’ attached to the factors from the interview. In naming the themes, the study look out for sub-themes addressing similar issues and possibly conveying same intents. These were grouped together under a common name.

While the content counts, themes developed, the major and minor factors extracted cannot be taken at surface value to determine the criticality, severity or importance of the factors influencing wider OSC adoption, all these points together inform the constructs developed and survey questionnaire development structure. The interview analysis, in line with interpretivism principles, ensured that the codes are not understated or overstated (Patton, 2002). *See Appendix 8.* Only codes containing salient points, relevant to the theme under discussion, are employed at any given time. The analysis also ensured codes used generally cut across relevant respondents' submissions bearing in mind not every theme has all the respondents in-vivo at once. Only the in-vivo codes that could convey the sub-themes and themes being developed, strengthen existing OSC ideology, present, or represent additional contribution to knowledge in the field of study were used.

Table 5.3 provides the summary of qualitative findings, including the underlying issues in each theme with the supporting quotes.

Table 5. 4: Summary of qualitative findings and relevant quotes from textual Analysis for themes

Theme, With count of issues	Underlying Issues identified from themes	Quotations
Awareness (8 Issues)	Low awareness	“OK, I mean the level of awareness is relatively low. You know that's why I said for 4/10.” -R12 "In terms of awareness, probably low...and 2 at the very best " -R1
	Professional awareness	"I'm not sure that my friends that are not in the construction industry have much awareness of modern methods of construction, I'm not sure my circle of friends who are not in the construction industry have a true awareness of how things are done. OK?" -R6
	Existing awareness	"I would say there's a lot of awareness. There's a lot of publications. There's a lot of conferences. There's a lot of discussion. Several Companies have established modern method of construction departments and divisions within their companies, and so in terms of awareness, I think there is a large awareness, -that it exists"- R6
	Awareness level	“OK, I mean the level of awareness is relatively low. You know that's why I said for 4/10. And the level of adoption is within most of the major players within the construction industry.” -R12 "I think my awareness is probably seven or eight out of 10. However, that's not to say that every sector is particularly in favour of offsite solutions or modular solutions"- R2
	Awareness and adoption lie among majority stakeholders	"Yeah, I got. I think let's reflect on what I said at the beginning about when they go to conferences, you tend to see the same kind of people all the time. Would they invite person not in houses in? I don't know. Maybe, maybe not"- R4
	Increasing awareness	"...and the barriers..., I think they're slowly dissipating really like more and more people are realizing that we need to use modern methods of construction..."- R11

Theme, With count of issues	Underlying identified themes	Issues from	Quotations
			"I think offsite construction is becoming a more noticeable idea, more people are aware of it. And even in the 10-15 years since I was working extensively and designing offsite solutions, I think nowadays it far more common solution..."-R2
	Recreating awareness		"I believe that the best way to make this industry change is to showcase examples of success through innovation or change...And I think once we can demonstrate really good examples of successful innovation, that's how the industry will change. So, for me this is an amazing opportunity"- R2
	Awareness adoption.	not	"OK, I mean the level of awareness is relatively low. You know that's why I said for 4/10. And the level of adoption is within most of the major players within the construction industry."-R12
Perception and Attitude (8 Issues)	Attitudinal perception		"I don't know, I'm afraid..., I've had the only project that I've worked with really the construction workers were on board and keen to use the methodology that we had. But that's because they were pushing for it as well. So, that's the only exposure I've had is that they were keen for it." -R9
	Quality perception		"There is a perception, I think, public perception, perhaps that volumetric modular offsite is not as good quality as traditional build, but I don't think that that's true at all. So, it's a perception problem" -R5
	Monotonous perception		"I think there's a perception that it needs to just be boxes stacked boxes, but you know it's components. It is offsite construction doesn't mean you're designing the whole building. It's not the whole thing, and it's parts of the building which are all coming together in components so you know you can assemble these components in a number of ways." -R9
	Cost perception		"They just look at the quotation from the offsite construction quotation from the traditional constructor and say offsite is too expensive, we'll stick to what we know." – R7 "I think this is very often driven by cost and the cost consultants. I mean this comes up repeatedly when you're actually evaluating whether or not offsite construction is actually appropriate. The said people will

Theme, With count of issues	Underlying Issues identified from themes	Quotations
		look at the actual cost comparison and they look at the sort of construction cost, but they won't look at the wider value" – R8
	Preference for well-known Traditional Method (conservatism)	"The construction today is very conservative with a big C and the small C and so change is very slow. And just at the moment, most builders can build rubbish and sell it. And so, why would you change?"- R10 "So, I would say I would say across the board, there's a dependence on, and current reliance on the traditional methods."- R9
	Fear of unknown (protectionism)	"...so, people might think that if you automate things more that people will lose jobs and because there's less manual work to do"- R11 "So, you know a government comes into power, and then in power for five years in the UK until the next election. For a lot of them, particularly investors, companies who want to invest in offsite technology, the one thing they want is certainty. And certainty for an offsite manufacturer is longer than five years. Well, they don't want to do it."- R7
	Reluctance to change Resistance	"I build quickly and make a lot of money. Why should I change to steel frame or timber frame or volumetric modular? Why should I change? I've always done it this way. It works for me and that a lot of time. It is the challenge. It's the old school thinking, so it's the senior staff have been around for far too long. We've always done it that way. And for offsite to really grow, it needs a mindset change with some of the senior people in these businesses. And the only way that happens is for them to see the benefits "- R7
OSC Buildability	Design Constrains	"I think from one of the key parts of offsite manufacturing, offsite construction is actually the design stage and I think at the moment, there are some excellent architectural practices who are fully aware of how to

Theme, With count of issues	Underlying Issues identified from themes	Quotations
(8 Issues)		approach this, but probably the vast majority of architects in the country are still in the learning phase and or possibly more should be done, 'cause effectively designed for manufactured assembly is the kickstarts for the offsite manufacturing and offsite construction process" -R1
	Repeatability/Re-use	"I don't think anybody has thought that information, but I think what you find is that anything in which where there is repetition or the potential for repetition, then the offsite construction"- R1
	Building Style and Type	"I would say... the education sector, the healthcare sector... I would say residential, but probably a more multi-storey residential rather than individual housing residential. I wouldn't say it's suited to, at the residential sector, in terms of private residential sector." -R6
	Applicability to bespoke buildings	"There's no limitation in terms of the material, so then there's concern in terms of planning that the modular housing will all look the same. Well, that doesn't need to be the case because. The claddings that go on the outside could be changed every time." -R1
	Structural stability	"The party wall, so the separating wall or party wall between dwellings is staggering down the building. So, the load path disappears. And they missed the point that if you can get the buildings to stack well so the apparent blocks layout floor by floor repeating on each other." -R7
	Connection issues	"...the only thing that inhibits that is the risk that when you come and join sections together on site, 'cause it still has to be built in sections, that if those sections don't come together in the right way, and so there's a fear of that not working when it comes to put together" -R6
	Inflexible nature of OSC	"All of the decisions have been made, and there's very little opportunity to change things..." -R2. "You wouldn't have that same level of flexibility outside like offsite methodology, because you have to stick to the work which has been done originally pre-planning" -R1

Theme, With count of issues	Underlying Issues identified from themes	Quotations
	Better tolerance for assemblage	"Operationally, functionally, it should actually be far more efficient because, as I said before on tolerances, the building tolerances are far better." -R7
Productivity (6 Issues)	Digitalization/tech accommodation,	"I think probably offsite construction failed in the 20th century because we didn't have a mature kind of digital technology to kind of knit it together.... To do offsite well, you need a sort of good digital tag behind you, and you also need a good assurance model as well" -R4
	Improved production process	"You've got idle equipment that's sitting on site that's not being used all the time, but a factory can operate 24 hours a day if you if you need it to, and if you've got the systems in place to do that" -R11
	Standardization	"...and to improve productivity, one thing we can help to do this more is to increase standardization and in doing that to improve interoperability between systems" -R3
	Waste reduction	"We in traditional construction methods are extremely wasteful. And in my lifetime, there have been numerous reports that suggest that as an industry we waste between 20 and 30% of the materials we procure...Yeah, some even say 40%.... Indeed, who knows what the real figures are, but of course waste doesn't only occur in material losses, it's in rework and inefficiency and processes and all that sort of thing"-R2
	Improved performance	"...and people are realizing that through building in a in a factory environment, you've got a greater level of quality control. You can use machines and equipment to install things like insulation, and you can better guarantee that the building is going to meet their performance requirement" -R2
	Co-ordinated work force	"So regardless of weather conditions, or you know what restrictions, there you can bring people under one warehouse and achieve results" -R12
Timesaving (3 Issues)	Time Saving	"I know one of the projects we did, which is, the Grand Hospital in Wales and part of it was to save about 233,000 hours by introducing offsite construction components" -12

Theme, With count of issues	Underlying Issues identified from themes	Quotations
		"Also, I think that the saving time taken factor is ultimately I think the biggest win." -R9
	Speed	"So, I think a big a big factor was the speed of construction..., because they wanted to be able to build the two towers- those two towers with 25 stories without any external scaffolding." -R9 "... one of the examples I suppose it benefits in offsite is this speed of delivering, brilliant speed of assembly. I mean, I've worked a long time in the house building industry and potentially the ability to erect a house in a day is the major driver for homes builder" -R2
	Ability to avert harsh weather condition.	"If we think about the way our industry has to operate on construction sites, it's a very hostile environment in terms of weather in terms of traffic movement in terms of heavy materials having to be moved, in terms of complex structures having to be delivered." -R2
Stakeholder Influence (7 Issues)	Decision Making	"...it is going to be different if you go down one path then the other path. I think it's just whether you actually go down that route. What's is much trickier is if you get to a certain level of design development, and then you start thinking, actually do I want to go to offsite? Then it becomes trickier to move-switch over." -R6
	Early Decision	"...so, most people that use offsite is an afterthought, so they don't plan it before any at the start of the project, and so they decide to go to the thought of using offsite halfway into the project. And so, if they want this solution, it is that they should think about it from the beginning of the project" -R5
	Client	"I guess for me, I'm further down the full chain when it comes to procuring. So, I'd say the person who more influences it is my client." -R8
	Stakeholder engagement and participation	"Similarly, you know the cost consultant needs to think how will this project be of lesser duration? will the overheads on the project be less? Will there be less waste? So, I think the industry is recognizing that to

Theme, With count of issues	Underlying Issues identified from themes	Quotations
		collaborate better and engage at an early stage is the really major way to make an offsite solution work." - R2
	Project goals	"I don't think that you should ever go into a project, say, right, I want to do this building, I want to do this housing development, and I want to do it offsite. I don't think that's the right decision to make at the start. I think when you want to plan any project, you have to think about what's driving the project. What are your objectives, what are your outcomes? What are your values? And then use that to drive how you want to kind of deliver it." -R4
	Communications	"So, these are all kind of organizations with slightly different focuses and sometimes they don't sort of communicate, come to each other very well which kind of leads to the criticism and the kind of fragmentation of the industry; wherever that stands, personalities or not, I don't know."- R4
Construction Industry Enterprise (7 Issues)	Complex nature of Construction market	"...and of course, you also need people who have that knowledge- the knowledge of the market. Many people really want to go into offsite. They don't know what the offsite market looks like. And when they start failing, they say offsite is not good, offsite is not good because they don't have the knowledge- they don't know the offsite construction model" -R5
	Fragmented nature of the construction industry	"Well, I think it needs to be helped along by government because I think the construction industry is probably too fragmented to do much without some sort of oversight from government or through regulation." -R3
	Market readiness	"There can be supply chain issues in terms of market availability, the capacity of the market to provide volumetric solutions. So, I think we always have to be wary of that" -R3
	OSC Business/construction model	"And when they start failing, they say offsite is not good because they don't have the knowledge- they don't know the offsite construction model" -R5

Theme, With count of issues	Underlying identified themes	Issues from	Quotations
	Need for adoption and readiness to promote it	OSC and to	"I think the UK has to find an alternative to his traditional methods...We were absolutely horrified at how poor the results were, despite the fact we thought we built the buildings to a high standard. And inevitably, the loss of air the leakage was through poor workmanship which we think would probably have not been there had it been offsite by solution in a factory-controlled environment, etc." -R2
	Funding and insurance	and	"...the other issues which come up are funding and warranties and obviously getting the lenders that they and the people of the finance people to understand again that the forest being built will last the same as perhaps a traditional building, traditional constructed apartment or house or whatever, that's in the residential sector. I think in the commercial sector and or in other sectors is getting the industry to recognize the value, not just the cost of some of the potential components and standardizing." -R1
	Accommodating OSC in construction SMEs	in	"...we know most of the larger project are done by the 20% of the larger company, while the rest are done by the smaller company. So, there should be some kind of incentive to support like companies in terms of training and to be able to adopt this process in doing this on their projects" -R5 Final one I want to mention on this is that offsite construction tends to be, say kind of flash technology level. It tends to be something only for tier ones... whereas you know, over 90% of the UK's construction industry are self-employed, either micro, you know one person builders or small or medium enterprises. How on Earth is offsite relevant for them? That's a big question I think needs to be answered." -R4
Environmental Sustainability	Whole life cycle		"It should really be that embodied carbon should really be at the forefront or whole life carbon even as well because we can't continue to build and demolish buildings the way that we're doing now." -R11
	Net Zero Emission		"...but actually, the most important driving force is meeting the Net-Zero emissions targets." -R11

Theme, With count of issues	Underlying Issues identified from themes	Quotations
(6 Issues)	Embodied carbon	"...but it's to do with embodied carbon targets and I think we need that because to induce the embodied carbon in a building... if you do more things offsite, then you can reduce that value as well as you can reduce embodied carbon." -R12
	Environmental Impact	"You know less time creating less of noise pollution and damaging the community, ... I think that is a major factor." -R10
	Sustainability	"...so quality is another one, and sustainability is a big thing as well with offsite construction" -R7
	Energy Efficiency	"Operationally, functionally, it should actually be far more efficient because, as I said before on tolerances, the building tolerances are far better. It's probably, I'm aware of a residential project in Mitcham in London, which was built as a frame construction, no water, no water supply was required on site. No scaffolding was required and the flats the Stafford Flats are operating at something like 20% of the energy consumption of a standard traditional build." -R1
Supply Chain and Logistics (6 Issues)	Secure pipeline of work	"...what else is inhibiting it? Not having a secure pipeline of work. So, if we want to invest more money in doing things using a greater level of digitization and automation, we need a secure pipeline of work and that needs to go 10 years Plus, we need to have that, we need to know that we're going to have a certain amount of housing to build offsite" -R12
	Supply chain	"The capacity of the of supply chain so again, in that case you know, I guess in theory it could have been an option, but it never was because it just wouldn't have worked" -R3
	Transportation	"I think that you know another main thing that might be a challenge might be transportations." -R12
	Production / manufacturing (policies,	"There's a couple of things here because it can have a detriment on social value if all of your manufacturer is done, say in one part of the country and your project is in the opposite end of the country. You're not going to benefit the local community there in that case." -R4

Theme, With count of issues	Underlying identified themes	Issues from	Quotations
	capabilities and locations)		
	Site/change challenges		"However, the challenges with modular because of the differences between the different suppliers and the units not necessarily being interchangeable. You do want them on board early on to be able to develop the design together. So, that can be a little bit hindering if you've got to go regimented through tendering processes " -R6 "Site layout works, so you have to program it in a particular way so that you would only deliver sips. So, there's a complexity on a site by site basis, and that and I think, that isn't an inhibitor, it's just a way of thinking that needs to be addressed like early." -R8
	Procurement pipeline		"...so, I think the main hindrance is the policies that are adopted for procurement..." -R6
Cost (5 Issues)	Capital cost		"I think clients are still concern about cost. It's not necessarily a lower capital costs, and sometimes, I think we find that people misunderstand what the capital costs will be. Certainly, sometimes cost consulting too, long with the issues of how you can make savings or tree limbs and so on. So, cost can be seen to be an issue. It isn't necessarily in particular. You look in the long term. But it can seem to be an issue" -R3
	Cost saving		"...and if you build a site 12 weeks quicker, these things are rented quite often in this space, so if you're not using that space for 12 weeks, all these savings should be lumped into the overall assessment, but they don't look at that"
	Cost control		"It's that you can better guarantee the cost because you've got more control over it through building in a factory environment" -R11

Theme, With count of issues	Underlying Issues identified from themes	Quotations
	Initial setting-up cost	"If you look at the building when it's in operation and an end of use and so people need to look beyond the initial direct costs " -R11 "... that capital investment... So, if there will be that kind of strategic alliance because you need huge capital investment to set up an offsite and factory and all of that so... "
	Cost certainty	"...before, it might have been an issue with having a clear evidence base that offsite manufacturing is a better way to build. People still perceive it as being more expensive; and what we're trying to get across to the industry is that you can better guarantee the cost because you've got more control over it through building in a factory environment." -R11
OSC Knowledge (5 Issues)	Academic Industry gap	"And I've been doing that for a while now, and so big constructors set up a specific hard perform for construction people, although they're not doing much at the moment to tell the truth, so it's a bit patchy whether school kids are going to kind of be inspired to go into construction or not. And it just depends on who they're able to meet for people, sort of coming to school and giving talks and so on." -R4 "A project organized by the construction Industry Training Board, recognize that the actual skills and knowledge about offsite construction, offsite manufacturing were quite limited..." -R1
	Improved educational curriculum to accommodate modern method of construction	"I think that modules dedicated to...well, that the modules are just dedicated on the surface. I did a bit of offsite construction, but it was just on the surface understanding, just a type of delivery." -R12 "I'm sort of aware there are one or two courses around that are focusing on this, but they tend to be post graduate or in further education rather than in higher education" -R3

Theme, With count of issues	Underlying identified themes	Issues from	Quotations
	Training		"... But I'm really think it's not being taken seriously enough yet. But I do want to refer back to the RIBA plan of work overlay to give them credit for that. But the other level I'm currently today, ..., is putting together a proposal for some offsite education. If you like, in things like colleges... So, these are young school leavers...." -R2
	Unavailable project Data	OSC	"Indeed, who knows what the real figures are? " -R2 "...on the number of OSC project data, I don't think anybody has thought that information, but I think what you find is that anything which where there is repetition or the potential for repetition, then the offsite construction" -R1
	Paucity of knowledge	OSC	"Secondly, is the lack of education around how to utilize offsite and where best to utilize offsite." -R9 "Probably a lack of knowledge generally across the industry, so we need to raise the knowledge across the whole construction sector, not just in architecture and what. It needs to be done early. Early design stages, because if you leave it too late, you lose the benefit, you lose the opportunity to maximize the benefits from it. So, I think we need to improve awareness and understanding and what it means to follow a DfMA process" -R3
Quality Performance (3 Issues)	Quality improvement		"I think the major for me would be being able to get improved quality for product; clients being able to get value for their money" -R12 "...and for it to be delivered more efficiently to a higher standard and to address the performance gaps that we're seeing so often, buildings are designed to meet a certain energy performance." -R11

Theme, With count of issues	Underlying Issues identified from themes	Quotations
	Controlled production environs	"...you know if you produce your component in the in the factory condition, - a controlled environment, you achieve more quality" -R5 "If you if you go into 21st century car plant (which MMC production is mimicking), it is incredibly clean and quiet and and everybody is extremely safe, and the end result is of the highest quality." -R2
	Quality control	"... so, there's a real issue around quality and quality control, so I think we need to look at that" -R10 "...and quite often the steps in the installation, or there's too much timber, in the system, the system which you know is temporary, it just means it doesn't perform quite so well. Firmly, you have more thermal breaks and that type of thing, more thermal bridging, so there's real issues around quality..." R10
Government Policy and Interventions (3 Issues)	Planning Regulations	"On high rise units, that actually can reduce the number of dwellings that you can build. So, if you're looking at something like a 20 story development, you may find that because each story is slightly higher than in a traditional solution, you can't actually build as many stories. If the planning constraint is on the overall height of the building. So, there's another negative if you like, in the residential sector at least." -R2
	Government policies	"... so government wants private developers to build all the housing, and that's policy and but they have put this great policy demand and said we want 300,000 new homes a year for the next few years so they kind of push that through the local authorities and then the local authorities have to push that out to private developers through their local development plans" -R4
	Government interventions (incentives)	"I think the government has come up... It's the only place government coming basically with a presumption for offsite which is a good thing, which is an encouragement. I think, but this hasn't been backed up by perhaps encouraging investment.... Perhaps more incentives certainly needed for the investment into the

Theme, With count of issues	Underlying Issues identified from themes	Quotations
		actual manufacturing capability. ... I'm in two minds about whether how much intervention there should be, or not any intervention." -R1
Health and Safety (2 Issues)	Work-Life Balance	"You don't have to travel miles to site every day and then travel miles back every day so from workers point of view, I think it it's a kind of win situation that if you could still be working but doing it somewhere local to your home and not kind of traveling because you reduce the number of people on site, I think that's probably one of the first major benefits of offsite that we've kind of said before." -R4
	Safety	"One of the things we've got in offsite construction, the benefits are very much health and safety" -R7 "On the project that I worked for, and I think major factors, I would say of those are probably quite measured, to be honest, because safety is obviously a big factor because, it's like a priority for contractors to..." -R9

See *Appendix 8* for detailed discussion on thematic analysis.

5.6.4 Inferences from The Findings and Discussions:

The findings of the OSC interviews draws inferences on the themes identified in *Table 5.3*.

Some of the major points from the thematic analysis are highlighted below:

There is awareness and the level is not as low as generally thought, though much of the existing awareness is domicile with industry professionals. Adoption level is still incredibly low, though some form of improvement seems to have occurred in recent years. Perception is still a prevailing influencing factor on OSC. However, there is an improvement in acceptance in recent years. A greater attitudinal resistance experienced has to do with age and experience.

OSC does not really contribute significantly to Work-life balance though it brings about some form of improvement to safety and how work is conducted.

Early decision to engage relevant stakeholders and communication synergy would significantly improve OSC adoption. The UK government has given a lot of visible, and tangible supports to increasing adoption of OSC within its construction sector and wider populace, however, they can do more through legislating more mandatory policies and more incentive provision.

Despite observed OSC awareness among industry professionals, there seem to be a general low knowledge about OSC-the modality of its business and the construction methodology details. Industry professionals seem ready for the shift in the industry but same cannot be said of the construction product manufacturers or industry workers. However, from the vast number of OSC manufacturers listed on Kier website, the UKCI OSC manufacturers is believed to have taken some steps ahead in increasing OSC adoption. Much cannot be said of the industry workers in this regard.

Construction industry SMEs are an integral part of the construction industry. There should be plans to accommodate them in the transitioning program.

Though no follow up question was asked about supply chain management, all the interviewees touched on it. It was deduced that SCM showed more inhibiting constituting factors than any other theme in the study.

While the findings from the qualitative approach provided insights into how critical some factors are to OSC adoption in the UK, the level of such factors' criticality could not be concluded upon. The interview finding however provided rich textual understanding of variable and constructs used to develop the survey questionnaire used to gather quantitative data for measuring and establishing the criticality of the identified factors and issues. The next chapters detailed the analysis of the quantitative approach, including selection of the most critical factors and the development of suitable OSC adoption predictive model.

Chapter Summary

Interview is a type of inductive knowledge contributing exercise that makes specific observations(s), recognises patterns in the observations and draws inferences from the observations. The observations may generate tentative theories, upholds or extend existing theories, or lead to establishing a new theory or knowledge. A major takeaway from the interview is similar to the observation in the SLR- lopsided knowledge about OSC concept, fuelled by absence of project data for pragmatic information and decision. Reported factors have underlying factors that are potential root causes. Also, there are no true boundary lines around factors influencing OSC adoption yet.

With the pockets of rays of hope and light observed on the wider adoption of OSC from the interviews, the study posits that there is a possibility of increased adoption in years to come if the identified factors can be addressed as quickly as possible and pragmatically.

CHAPTER SIX

6.0 QUANTITATIVE APPROACH (QUESTIONNAIRE ANALYSIS)

Chapter Overview

The interview content and thematic outcomes were analysed for common factors and themes (See chapter 5). The outcome was triangulated with the UK-focused literature review factor themes (See chapter 2) to develop a survey questionnaire used for gathering quantitative data (See Chapter 4 and Figure 4.2). In this chapter, the quantitative data was analysed using descriptive analysis and exploratory analysis to prepare the data for Feature Selection (FS) and Machine Learning (ML) approach (See Figure 6.1).

Preamble

For context, the dependent variable (DVMain) responses have 5 classes (1-20%, 21-40%, 41-60%, 61-80%, 81-100%). A dependent variable is the variable being analysed for (that is, the target variable), and in this case, the adoption level of OSC in the UK. Due to this multi-class nature of DVMain, a multi-Class approach (MCC), using Mode missing data imputation was first used, but owing to poor Machine Learning (ML) accuracy results obtained at the end of the exercise, KNN missing data imputation was tried. Still with no significant improvement observed, the entire exercise was repeated for Binary Classification (*See last paragraph of Section 8.4.1*).

Therefore, in quantitatively analysing the factors, two (2) missing data imputation was employed, namely Mode and KNN missing data imputation. Also, the reliability of the survey responses was examined using Cronbach's alpha index. Correlation analysis was conducted to

ensure no two factors contributing the same effect were selected for further analysis. Feature selection techniques were applied to analyse the criticality of the factors used in creating predictive models for OSC adoption. Owing to poor results observed during Multi-Class Classification (MCC), the experiments were repeated using Binary Classification (BC) for both Mode and KNN missing data imputations. In establishing the most critical factors influencing OSC adoption in the UK, the study used 10 FS algorithms that apply to classification exercise from the popular ones, iterating through nine random states. These FS results identified common and significant features across the 10 FS methods, generating new datasets for model development. *See Figure 6.1* for Quantitative Analysis Approach to Model Development.

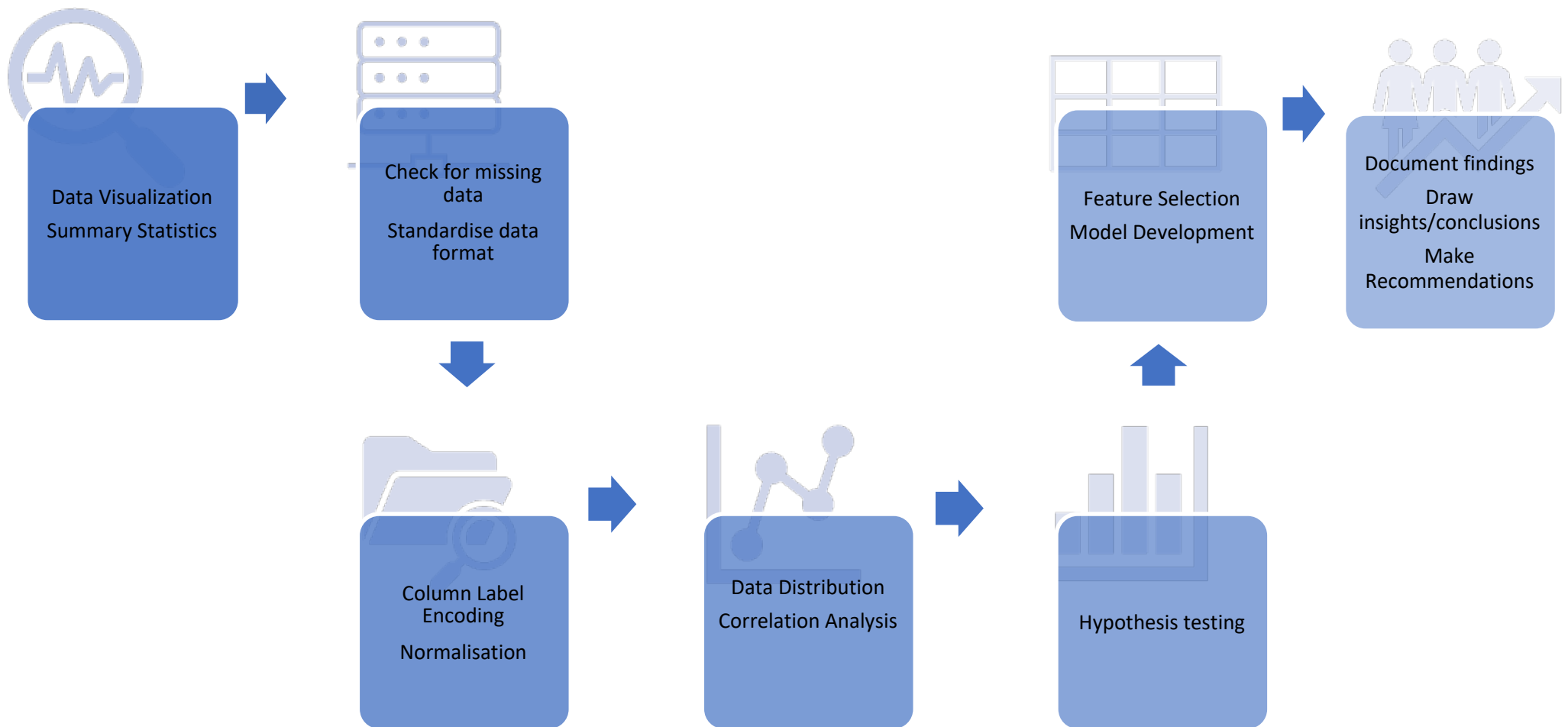


Figure 6.1: Quantitative Analysis Approach

6.1 Data Profiling (Overview of survey questionnaire)

6.1.1 Data Demography

To commence the quantitative data analysis, the survey response was exported to Microsoft Excel from MS Forms. The raw data was duplicated to ensure any pre-processing done do not impact the original data content. The duplicated version was renamed and used for exploration. However, it was important to visualise the data pattern first because statistically analysing data in a table without understanding the context of the data complicates understanding the data (Pooja, 2023).

From the three hundred thirty-seven (337) attempts made at filling the survey questionnaire between November 14, 2023, and August 9, 2024 (269 days), three hundred twenty-eight (328) respondents consented to taking the survey, three (3) persons declined taking the survey, while six (6) persons considered the ‘maybe’ option. It was observed that the six (6) people, however, took the survey. This option was added to the research approach because a yes or no option may limit the number of responses achieved. An optional question on why the survey declined was included in the questionnaire to provide improvement opportunities in further (OSC adoption) studies; unfortunately, only one (1) response was received. The response rate was difficult to measure owing to the use of social media platforms to snowball survey response. However, the average response time observed was 58 minutes 56 secs.

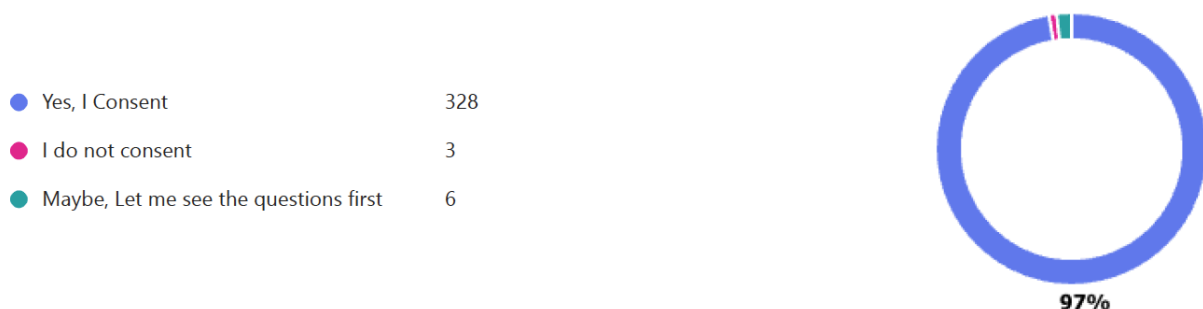


Figure 6.2a: Consent to taking the survey.

From the three hundred and thirty-four (334) respondents who consented or considered taking the survey, 311 of them noted they had been involved in construction-related project(s) in the UK where Offsite Construction (OSC) was/is used or where a part of the project(s) was/is OSC. Twenty-three (23) people have not been involved in any project(s) in the UK where Offsite Construction (OSC) was/is used for the project or where a part of the project(s) was/is OSC. Four (4) of the 23 that had not been involved in UK OSC project(s) have had OSC considered for their projects, but it was not eventually used. Thus, nineteen (19) people do not have experience on OSC-related projects, according to the survey response review. Data related to these 19 respondents were therefore dropped from the Excel data before further exploration in addition to the 3 data rows that did not agree to taking the survey. Thus, a total of 337 datapoints (315 valid responses and 22 (19+3) invalid responses) were collated in Excel for further data transformation and cleaning. *See figures 6.2 (a-c).*



Figure 6.2b: Number of respondents who ever worked on or have been involved in any project(s) in the UK where Offsite Construction (OSC) was/is used for the project or where a part of the project(s) was/is OSC.



Figure 6.2c: Number of respondents who considered OSC for their projects or not.

Below is a demography of the UK construction industry professionals who participated in the survey. Most responses came from Architects (85), followed by Project Managers (53) and then OSC Marketers (41). The least responses came from Mechanical and Electrical Engineers (4 each). No response was received from Others.

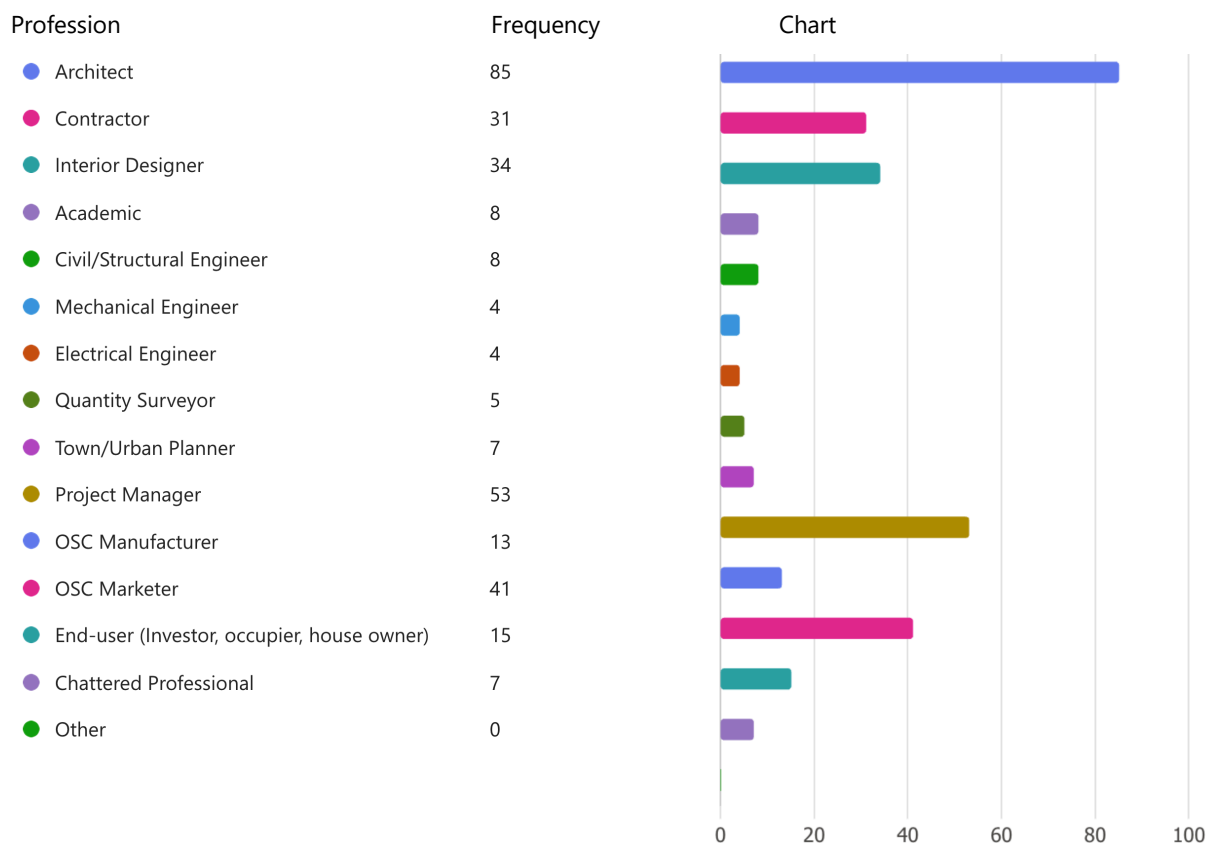


Figure 6.2d: Respondents' specialization.

The responses reflected strong academic background of responders, with responses coming from master's holders (145), Bachelor (69) and PhD (48). One (1) response came from 'Other', two (2) responses from NVQ and OND, and nine (9) from SVQ holders, while no responses were received from GSCE.

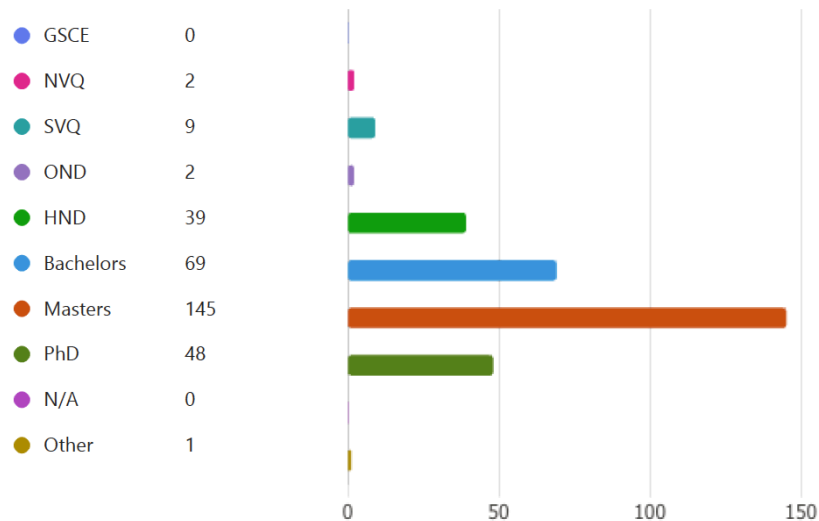


Figure 6.2e: Respondents' education qualification.

Respondents' demography also reflected good knowledge of construction and years of practice within the construction industry. Sixteen (16) respondents (7.44%) reflected less than a year experience, ninety (90) respondents (41.86%) reported 1-5 years' experience, while 209 (66.35%) respondents showed 6 years of experience or more.

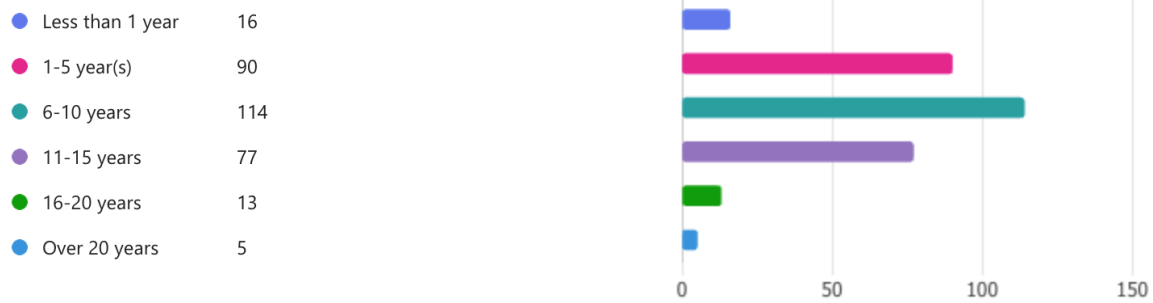


Figure 6.2f: Number of years respondents have been in construction-related practice.

The demography further revealed that the responders are not just knowledgeable on general construction but have good knowledge of OSC and have participated in one form of OSC project or the other. *See figures 6.2 f and g.*



Figure 6.2g: Years of construction(related) practice involving the design or/and construction of OSC project.



Figure 6.2h: Number of OSC projects respondents worked on, including any current one.

Lastly, the demography showed that most responses came from England (159), followed by Scotland (61), while seven (7) responses were received from the Isle of Man.



Figure 6.2i: Location of OSC projects respondents worked on.

The survey response contained one dependent variable (1) and one hundred and two (102) independent variables. To tag the column for easy reference during analysis, they were labelled according to the constructs they measured; for example, Awareness constructs were tagged AW, perception constructs were tagged PP, and so forth. while the dependent variable was tagged DVMain (*See Table 6.1*). The data size (103 variables) and with each variable maximum cardinality being 5, the dimensionality of the data size was managed without the curse of dimensionality or high-dimensionality computational challenges.

Table 6.1: Construct Variables Tagging.

S/No	Survey Question (Variable Name)	Construct	Variable Tag
1	Specialization (If not a construction professional, please tick others):	General Information (5 Items)	GF1
2	Highest Qualification (If no formal educational at all, please tick N/A)		GF2
3	How many years have you been in construction related practice?		GF3
4	How many years of your construction(related) practice involved the design or/and construction of OSC projects?		GF4
5	How many OSC projects have you worked on, including any current ones?		GF5
6	Location of the selected project:	Project Details (11 Items)	PD1
7	What type of OSC concept was majorly employed for the project under consideration?		PD2
8	What class of building/infrastructure was developed for the project?		PD3
9	What type of residential building was/is it?		PD4
10	What type of Multi-storey building was/is it?		PD5
11	What type of institutional building was/is it?		PD6
12	What is the size of your project site?		PD7
13	What client type owned the OSC project?		PD8
14	What was/is the OSC project duration?		PD9
15	How long did/would the entire project duration take?		PD10
16	How long would it have taken the project if OSC was not considered or used?		PD11
17	What percentage of the project under consideration was OSC? You may use an approximate figure where you cannot provide exact figures.	Dependent Variable	DVMain
18	Awareness of client-related stakeholders on the potential (benefits) of using OffSite Construction (OSC) for the project? E.g., investors, financiers, clients, etc.	Awareness Factor (5 Items)	AW1
19	Awareness of professional stakeholders on the possibilities of using OSC for the project or not? E.g., architects, engineers, contractors, consultants, and artisans, etc.		AW2
20	Awareness of project end-users regarding the decision to adopt OSC on the project or not to.		AW3
21	Awareness of planning authorities: To what extent was the knowledge level of planning authorities concerning Offsite Construction (OSC) construction methodologies influence their decision to appro...		AW4
22	Awareness of Construction product manufacturing companies: To what extent was the knowledge of OSC		AW5

S/No	Survey Question (Variable Name)	Construct	Variable Tag
	project component/module production considered when planning the project?		
23	How much consideration was given to assembling the whole OSC project team for the project? (not just a sub-team the respondent is part of)	Project Team and Management (6 Items)	PTM1
24	How much consideration was given to project team's readiness to utilize OSC for the project?		PTM2
25	How much consideration was given to project team's possible request to use OSC for the project?		PTM3
26	How much consideration was given to Project team's competence to use OSC on the project?		PTM4
27	How much consideration was given to contractor's proficiency to effectively implement the OffSite project being considered?		PTM5
28	How much consideration was given to availability of training for project team members on the use of OSC for the project?		PTM6
29	How much consideration was given to Awareness, Desire, Knowledge, Ability and Reinforcement (ADKAR) approach in the use of OSC for the project?	Project Knowledge and Data (5 Items)	PKD1
30	How much consideration was given to availability of past OSC Project Data to support adopting OSC for the project?		PKD2
31	How much consideration was given to availability of communication tools to support adopting OSC for the project?		PKD3
32	To what extent was the use of OSC project collaboration and information-sharing platforms, such as email, collaboration software, and project management tools, taken into account for project team		PKD4
33	How much was the potential of OSC to generate and collate post-construction data for monitoring, evaluation, and reporting taken into account?		PKD5
34	Negative historical perception of OSC/prefabricated buildings on the project (the mindset that OSC could fail like it did when it was first used around mid 1900s to resettle war soldiers and their...	OSC Perception Issues (7 Items)	PP1
35	The quality perception of OSC/prefabricated projects (a belief that OSC quality is not as good as traditional construction projects)		PP2
36	Durability perception of OSC buildings (a mindset that traditional buildings are more durable than OSC buildings) on the project		PP3
37	Cost perception (a belief that OSC is more expensive than traditional construction project) on the project		PP4

S/No	Survey Question (Variable Name)	Construct	Variable Tag
38	Monotonous perception (A common misconception that OSC is limited to box-like designs and unsuitable for creative or flexible architectural solutions).	Project Attitude (7 Items)	PP5
39	End-users' perception of OSC buildings on the project		PP6
40	Perception of real estate professionals in terms of how end-users, e.g., rentals, may view the use of OSC on the project.		PP7
41	Conservative Attitude of project stakeholders and team (Preference for well-known Traditional Method over OSC as a new method of construction)		PA1
42	Protectionism (Fear of the unknown regarding adopting OSC for the project)		PA2
43	The reluctance of client-related stakeholders to change from the traditional method of construction		PA3
44	The reluctance of professional stakeholders to change from the traditional method of construction		PA4
45	Resistance from client-related stakeholders to adopting OSC for the project	Design and Construction Factors (15 Items)	PA5
46	Resistance from professional stakeholders to adopting OSC for the project		PA6
47	Resistance from end-users to adopting OSC for the project		PA7
48	Design lead time (Is the amount of time required before freezing OSC design quicker or slower)		DCF1
49	Design and construction flexibility (Are OSC designs well adaptable to changes as traditional designs?)		DCF2
50	Design abilities of OSC designers (How well do designers meet OSC production requirements)		DCF3
51	OSC Building (Construction) material quality (a belief that OSC construction material is not of quality as traditional construction material)		DCF4
52	OSC Building (Construction) material durability (a belief that OSC construction material is not as durable as traditional construction material)		DCF5
53	OSC type used (How much consideration was given to OSC type e.g., volumetric, panel, pods, or components?)		DCF6
54	Building type (In OSC decision-making, how much was the project's building type, such as private, bespoke, commercial, institutional, etc. considered?)		DCF7
55	Ease of on-site OSC components/modules assemblage		DCF8
56	Buildability of the project design (How much consideration was given to the buildability of the OSC design for the project?)		DCF9
57	Scalability (Repeatability of design and project modules)		DCF10
58	Standardization of modules		DCF11

S/No	Survey Question (Variable Name)	Construct	Variable Tag
59	Structural Performance of connected modules		DCF12
60	Production quality control		DCF13
61	OSC components tolerances		DCF14
62	Timesaving (Speed, possibilities of overlapping schedules during production, quick on-site works)		DCF15
63	Supply Chain Management	Supply Chain and Logistics (14 Items)	SCL1
64	Availability of manufacturing company(ies), nearby or far away, that can produce the project's desired OSC modules or components		SCL2
65	A secured pipeline of work (the ability of the production company to meet project demands during the project period)		SCL3
66	Transportation means for components or modules		SCL4
67	Consideration/Availability for Specialist equipment and tools such as Crane management on site		SCL5
68	Truck size that fits module/component size		SCL6
69	Road width that fits truck size		SCL7
70	Access Road to the site that fits truck size		SCL8
71	Number of access(es) available to the project site		SCL9
72	Ratio of site size to buildable area		SCL10
73	Site Hedging (Availability of site storage area for components and modules)		SCL11
74	Unfavourable weather conditions during project period		SCL12
75	Redundancy of local workers (Were you worried about how many construction workers would be jobless if OSC was adopted?)		SCL13
76	Shortage of skilled OSC workers		SCL14
77	Planning regulations on OSC applications in relation to traditional construction applications?	Policy, Regulation and Sustainability (12 Items)	PRS1
78	Government policy on construction projects, e.g., policies on saving 33% cost, 50%-time, net-zero carbon reduction, achieving 55% premanufactured value (PMV) etc.		PRS2
79	Government regulations (e.g., restrictions on heights, number of floors, etc.)?		PRS3
80	Government incentives (How much consideration was given to encouraging rewards on the use of OSC e.g., issuing of green card, BREEAM cert (UK LEED version), on the use of OSC in relation to traditional construction.		PRS4
81	Availability of dedicated OSC construction regulations, monitoring and inspection.		PRS5
82	Availability of industry practice guidelines on use of OSC for projects		PRS6

S/No	Survey Question (Variable Name)	Construct	Variable Tag
83	Environmental Sustainability (How much of OSC sustainability impact did you consider in adopting OSC for the project)		PRS7
84	OSC Building whole life cycle (Overall OSC building performance during building lifetime when compared with traditional construction)		PRS8
85	Energy efficiency		PRS9
86	Carbon emission		PRS10
87	Waste reduction		PRS11
88	Safety consideration		PRS12
89	Client's business model	Construction Market and Cost (15 Items)	CMC1
90	Developer's business model		CMC2
91	OSC Contractor's Business Model (How suitable was the OSC business model for the project)		CMC3
92	UK construction industry market readiness for OSC buildings		CMC4
93	Nature of the construction industry (fragmented and complex)		CMC5
94	Availability of construction industry SMEs' support for the OSC project		CMC6
95	Financial viability of OSC projects		CMC7
96	Overall OSC project cost		CMC8
97	Initial setting up cost (1st instalment paid to kick start the project)		CMC9
98	Cost-saving potentials of using OSC for the project		CMC10
99	Cost control advantage of OSC during the project duration		CMC11
100	Cost certainty for adopting OSC on the project		CMC12
101	Funding (Securing funds for adopting OSC on the project)		CMC13
102	Securing Insurance (concerning adopting OSC on the project)		CMC14
103	Mortgage Accessibility (with respect to adopting OSC on the project)		CMC15

A total of 32,445 data cells (315 rows and 103 columns, DVMain inclusive) were wrangled for further analysis.

6.2 Exploratory analysis

6.2.1 Data Pre-processing for exploratory analysis

The data was first pre-processed in Excel, with few transformations. Some of the transformations were encoding the nominal and ordinal data columns with variable tags (*See Table 6.1*), following the construct they are under in the questionnaire sections. Some pre-processing done included removing columns that do not add value to statistical analysis to avoid ‘noise’ within the data, e.g., entry date and time, among others. The 22 invalid responses were removed from the rows as they do not qualify for exploratory or predictive data analysis. The data quality (DQ) was assessed for accuracy (spelling check), validity (syntax), completeness (missing values) and consistency (ensuring the same format). This approach has been used in some CEM research works (Ehwi et al., 2022; Wuni & Shen, 2019; Zhai et al., 2014). DQ was mostly applicable to the additional information provided and a few Likert scale responses. Most of the transformation took place on PD4-6 (*See Table 6.1*), where the DQ exhibited inaccuracy and inconsistency owing to dependencies on preceding questions. PD4-6 also showed incompleteness owing to the questionnaire format.

From the DQ checks, one hundred and fifty-one (151) missing values (that is, empty cells) were observed from the entire dataset (columns and rows), most of which are from the ordinal scale questions. Considering that most of the survey questionnaires were categorical, the demography questions are closed questions, leaving the respondents with no options to select from outside the question boundary, the issues relating to outliers do not surface from the dataset. No inconsistencies were observed in the data frequencies, and no duplicates were observed. Where a missing value is observed, the mode value of that column replaced the missing data points in that column (*See Figure 6.3*). The mode value was adopted because it

does not influence the categorical nature of the data, especially of the target variable, DVMain (Jerez et al., 2010; Statistics Café, 2017; University of St. Andrews, n.d.). Also, the mode value represents the general opinion of responders and has been well adopted in construction and non-construction research works (Statistics Café, 2017; University of St. Andrews, n.d.). However, to standardise the categorical values, label encoding was employed using unique numerical value for each Likert category. for example **1**= 0% (Not considered at all), **2** = 1% - 25% (Low consideration), **3** = 26% -50% (Medium-Low consideration), **4** = 51% -75% (Medium-High consideration), **5** = 76% -100% (High consideration).

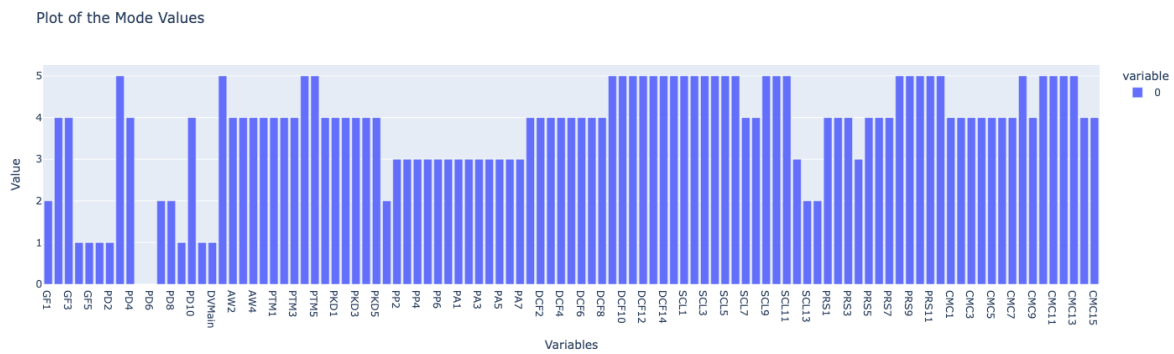


Figure 6.3: Plot of Mode Values

Also, detailed distribution of some randomly selected data variables was checked as recommended by (Ghasemi & Zahediasl, 2012; Sainani, 2012). This helps build an initial understanding of the dataset. Some of the variables are GF1, DVMain, PD5 and CMC15. (*See Figures 6.4 (a-d)*). *Figure 6.5* shows the distribution of the entire using histogram.

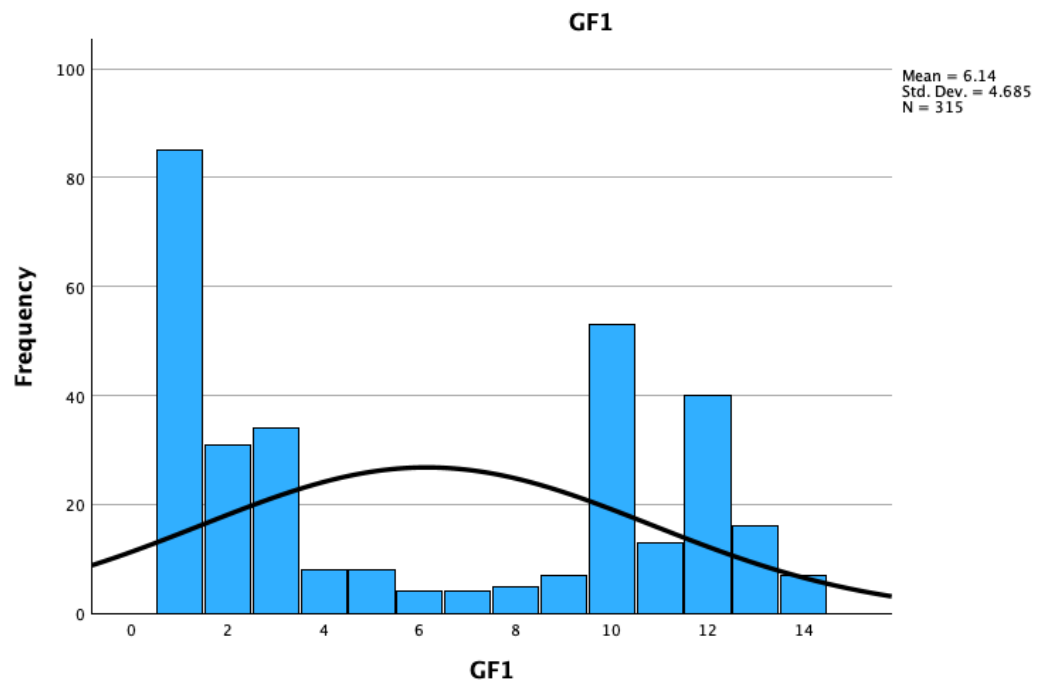


Figure 6.4a

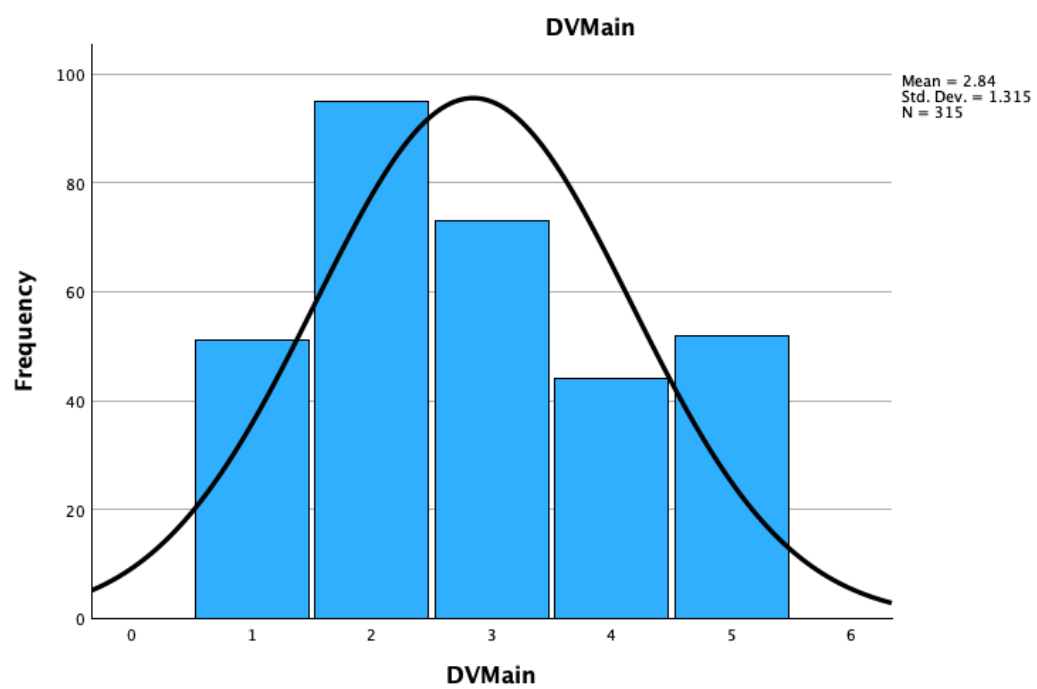


Figure 6.4b

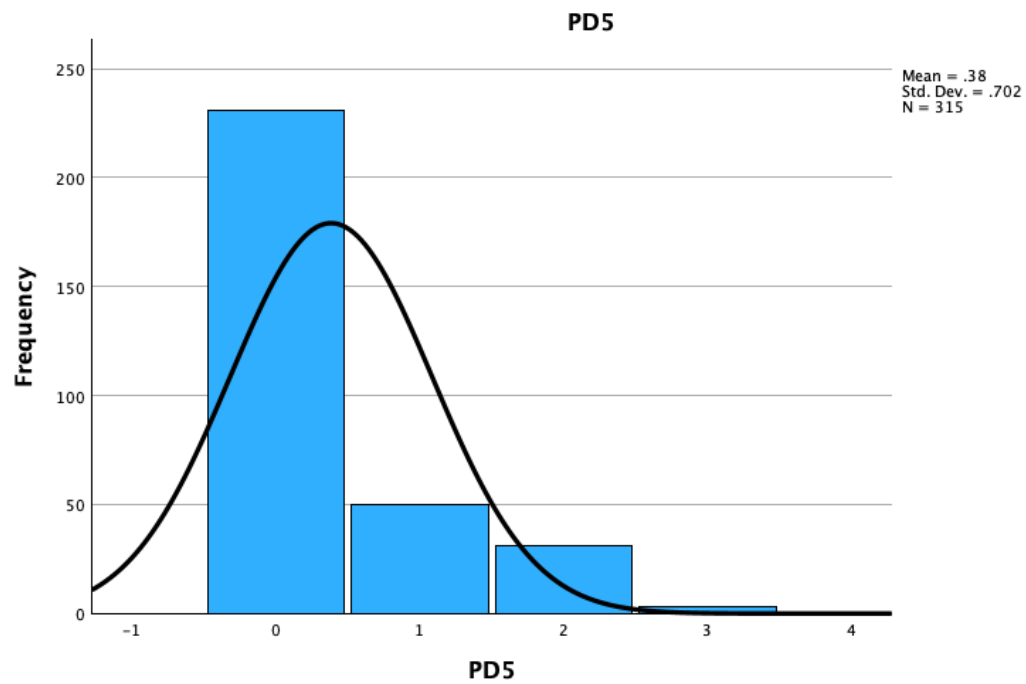


Figure 6.4c

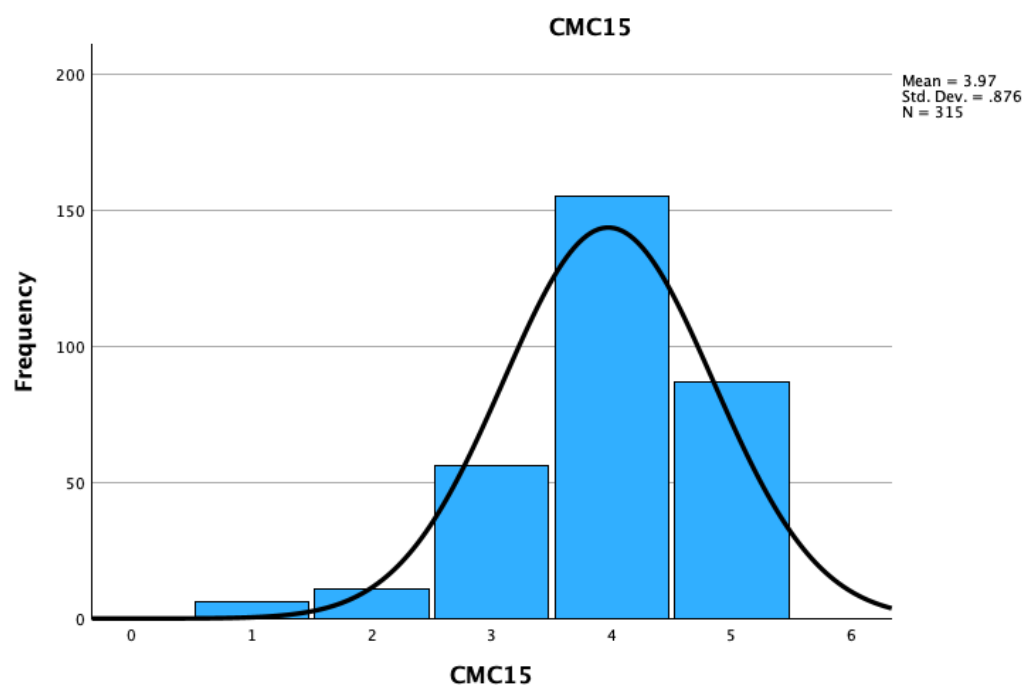


Figure 6.4d

Figures 6.6 (a-d): Exploring the distribution of some of the categorical variables.

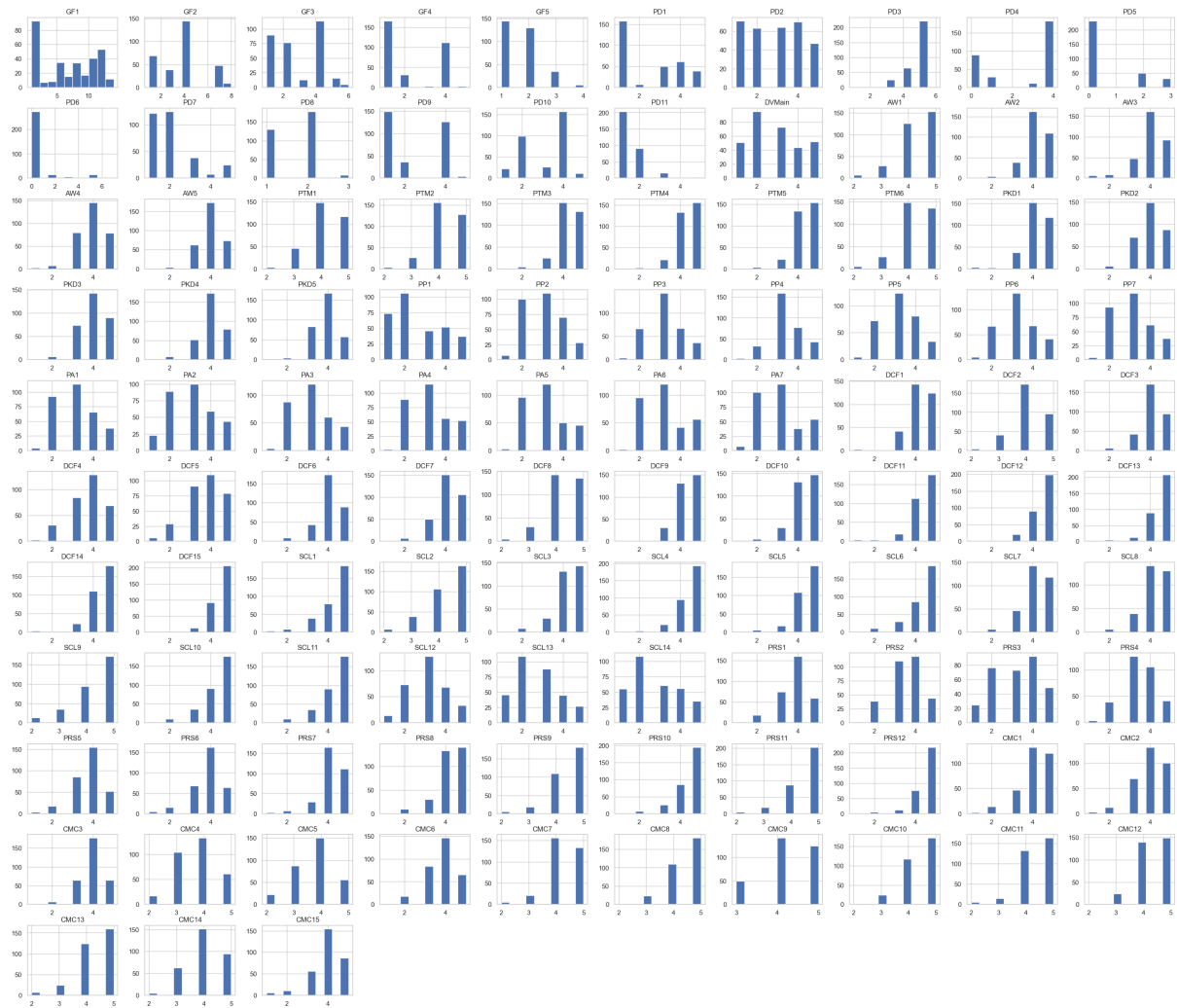


Figure 6.5: Visualizing the distribution of ordinal variables using histograms (A case of MCC Mode Imputation).

Following that majority of the data is not normally distributed, the data was standardised using MinMax Scalar (Patro & Sahu, 2015).

Handling Missing Data

The data was checked for missing values using a bar plot to visualize the different missing values and understand their patterns within the dataset.

Missingness can be at random, MAR, (when the probability of missing is within a particular group), not at random, MNAR, (when the probability of missing is not within a particular group and reasons are not known to the researcher) or completely at random, MCAR, (when the probability of occurrence depends on a dependent question or is same for all cases) (Zhou et al., 2024). Two types of missingness were observed in this dataset. The first type of missingness in this data is missing not at random (MNAR) because the missing cells are not within a group and the study does not know their reasons for the missingness. The second missingness, more prominent in Project Details (PD) questions, is missing completely at random (MCAR) because the answer of one question depends on the answer of a previous, resulting in a missingness for the non-selected options.

There are different ways to replace a missing value in a dataset (Alwateer et al., 2024). A missing value could be replaced with statistical techniques like mean, median or mode when there is a missing completely at random (MCAR) or missing at random (MAR). Missing values can also be replaced with ML model imputation when missing not at random is observed. Some complex ML algorithms that may be used include k-nearest neighbour, Multiple Imputation by Chain Equation, and the likes (Buuren & Groothuis-Oudshoorn, 2011; Jerez et al., 2010; Stekhoven & Bühlmann, 2012). These have been applied in domains such as healthcare, finance and environmental sciences. Hot deck imputation, maximum likelihood estimation, pairwise or likewise deletion and sensitivity analysis are other options that can be considered but were dropped because of the complexity involved in their use. The option of pairwise or likewise deletion was also dropped to avoid reducing the statistical power of the relatively small data size as these types can require complete deletion of the data row leading to loss of

data (Sterne et al., 2009), while some advanced imputation techniques like KNN can be used for the most frequent value among the neighbours in a categorical data (Alwateer et al., 2024).

A total of 151 cell values (cells in rows and columns) were missing from 32455 cells of 315 data points (rows). (*See figure 6.6*) This accounts for 0.47% of the entire dataset, well below 5% acceptable threshold (Little & Rubin, 2019). Since the percentage value of missing data is very low, the goal of replacing missing data largely focused on maintaining variability and avoiding bias within the dataset without unnecessarily losing or distorting the data structure (*Multiple Imputation by Chained Equations*, n.d.).

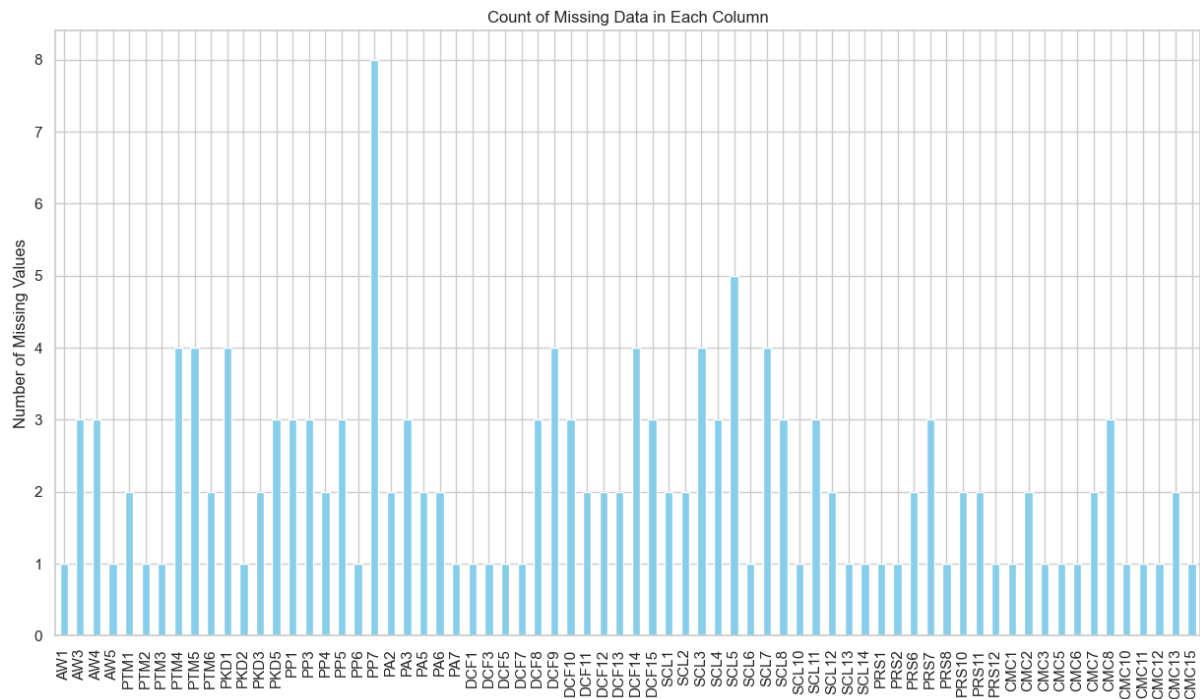


Figure 6.6: A graphical count of missing values from the survey response

The mode of each column replaced the missing values for that column because the mode values have been found to manage the extremes of a dataset, maintain modal tendency and minimise the risk of inflating variance or skewing distributional assumption (Buuren, 2018). Moreover,

since the missing data is not large, replacing it with a mode value preserves the data size, structure and variability (Dong & Peng, 2013). Mode imputation has been established to apply predominantly to ordinal data and data with skewed values (not normally distributed or with long tails) (Allison, 2001; Enders, 2010), as observed in some of this data frequency analysis.

However, when the results from multi-classification did not show good accuracy still (after feature engineering, feature selection and hyperparameter tuning for model development), KNN imputation was introduced to replace missing values as a second option for model development.

6.2.2 Internal Reliability

Reliability tells how consistently something is measured by a method. It implies if a method measure something under the same condition over and again, the outcome should be consistent. While the qualitative and quantitative reliability analyses are similar in function, the first addressed interviewees' reliability, which has been ensured above (*See Section 4.4.4*), and this section addressed quantitative response reliability. There are four types of reliability in a quantitative study, namely Test and Retest, Interrater, Internal consistency and Parallel forms. For the purpose of this study, only internal consistency was examined because it assesses the degree to which items within a scale or construct are consistently measuring the same underlying concept (Gliem & Gliem, 2003). Moreso, it is commonly used and accepted in most empirical studies-including social and behavioural sciences, it is good for multi-item scales, easy to calculate and interpret with no need for multiple administrators (Tavakol & Dennick, 2011).

Internal consistency measures the correlation among items in a test that are intended to measure the same construct (Bhatnagar et al., 2014). It has been well adopted for questionnaire data (Meadows, 2003). For this study, Cronbach Alpha, α , among others like Split-Half Reliability, Kuder Richardson formulas (KR-20, KR-21), McDonalds omega, among others., was the statistical measure used to analyse internal consistency because of its generalisability and popularity in research works (Morera & Stokes, 2016). The internal reliability analysis was done using IBM SPSS Statistics software V 29.0.2.0 (20).

Scholars have classified the categories of reliability outcome, denoted by α to be excellent where $\alpha \geq 0.9$, good where $0.8 \leq \alpha < 0.9$; acceptable where $0.7 \leq \alpha < 0.8$; (Razkenari et al., 2020) questionable where $0.6 \leq \alpha < 0.7$; poor where $0.5 \leq \alpha < 0.6$, and unacceptable where $\alpha < 0.5$ (Gliem & Gliem, 2003). Some other authors argued that alpha values of $0.6 \leq \alpha \leq 0.79$ is acceptable while $\alpha \geq 0.8$ is highly reliable (Adeniran, 2019; Nunnally & Bernstein, 1994). $\alpha \geq 0.7$ has generally been adopted for various construction-related studies (Alaka et al., 2017; Balogun et al., 2024; Wuni et al., 2020) and research works in other disciplines (Agapiou, 2022; Auperin et al., 1997; Bhatnagar et al., 2014; Haller et al., 2003; Vasileiou et al., 2018).

Reliability, α , is mathematically defined as:

$$\alpha = \frac{N * c}{v + (N - 1) * c} \text{ ----- Equation (i)}$$

Where:

N = No. of Variables,

c = average of covariance between factor pairs and

v = average variance.

This study evaluated the reliability of each construct according to the survey questionnaire structure (Okolie, 2023). The categorical (nominal) data of the demographic questions, the categorical (ordinal) data for the factor variables and the overall Cronbach alpha for the entire data are presented below (*See Table 6.2*). Items not contributing to the reliability coefficient of the Cronbach Alpha values and the study for each construct were not removed though they did not load to the required threshold, as in the case of GF and PD for example. They were included in the analysis variables because the overall Cronbach Alpha value is sufficient enough to proceed to analysis without excluding them. (*See Table 6.2*)

It emerged from the reliability analysis that two (2) constructs have $\alpha > 0.9$, three (3) constructs have above $0.8 \leq \alpha \leq 0.9$, four (4) construct has $0.7 \leq \alpha \leq 0.8$ and two (2) constructs have $\alpha < 0.5$. Project Details (PD) construct with $\alpha < 0.5$ is understandably so due to the dependency of the questions in that construct requiring only one option to be chosen, and where so, other values take 0. However, when PD4 was deleted from the construct, the α value became greater than 0.6, putting the PD construct above the poor zone category. The overall Cronbach alpha value is above 0.897, implying a near overall excellent reliability for the study data. Upon deleting GF1, the overall Cronbach Alpha, $\alpha > 0.9$ (0.925), becomes excellent and does not indicate any further item needing to be removed to improve it. (*See Table 6.2*) Since $\alpha = 0.897$ realised is very good, the entire data was used for further statistical and predictive analysis.

Table 6.2: Summary of Cronbach Alpha Reliability Report for each Construct

S/No	Construct	No of Construct Item	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Item	Construct Item deleted to improve Cronbach Alpha Value	New Cronbach's Alpha
1.	General Information (GI)	5	-0.138	0.464	GF1	0.602
2.	Project Details (PD)	11	0.406	0.564	PD4	0.634
3.	Awareness Factor (AW)	5	0.785	0.786	-	-
4.	Project Team and Management (PTM)	6	0.792	0.793	-	-
5.	Project Knowledge and Data (PKD)	5	0.786	0.786	-	-
6.	OSC Perception (PP)	7	0.914	0.918	-	-
7.	Project Attitude (PA)	7	0.954	0.954	-	-
8.	Design and Construction Factors (DCF)	15	0.877	0.883	DCF5	0.878
9.	Supply Chain and Logistics (SCL)	14	0.775	0.828	SCL14	0.829
10.	Policy, Regulation and Sustainability (PRS)	12	0.849	0.853	-	-
11.	Construction Market and Cost (CMC)	15	0.832	0.836	-	-
12.	Nominal Variables only	16	0.319	0.661	GF1	0.566
13.	Ordinal Variables only	86	0.942	0.944	SCL1, 2 & 6	0.943
14.	All variables (minus DV Main)	102	0.897	0.931	GF1	0.925

6.3 Hypothesis

6.3.1 Hypothesis Development

Following the findings from the literature review (*See Section 2.3.5*) and interview content analyses (*See Section 5.1 and Chapter 5 Summary*), the study observed some factors that are supposedly strongly influencing OSC adoption based on their frequency of mention. This suggested not all the variables or construct contribute equally significantly to DVMain. This

agrees with the proposition of Vilfredo Pareto's theory (Powell & Sammut-Bonnici, 2015; RISR Careers, 2021), which states that 20% of activities within an organization account for output of the other activities.

While the content analyses provided insights into the significance of some of the factors on adoption, these perspectives do not suffice for concluding that the said factors are truly significant to OSC adoption without statistical tests (Field, 2009). However, the identified factors enabled the development of hypothesis for factors influencing OSC adoption, thus shifting conclusions from opinion-base view to data-driven basis (Creswell & Creswell, 2018). To this end, hypotheses development and testing employed the quantitative approach to measure which variable(s)/factor(s) are statistically significant to OSC adoption in the UK and to what extent.

A hypothesis is a formal statistical proposition about a population parameter, derived from observed sample data (Emmert-Streib & Dehmer, 2019). In the context of OSC adoption, this approach facilitates the evaluation of whether the associations between specific factors (e.g., cost, skills, perception, policy) and the level of adoption are statistically significant or whether the relationship is due to random variation.

The analytical process begins with formulating a null hypothesis (H_0), which posits that there is no statistically significant relationship between the predictor and the adoption level outcome. This baseline assumption remains accepted until empirical evidence supports an alternative hypothesis (H_1)—that a true association or effect exists (Biau et al., 2010; Chén et al., 2023). These hypotheses were tested within a defined significance threshold (α), which represents the

acceptable risk of committing a Type I error—incorrectly rejecting the null hypothesis when it is, in fact, true.

The type of test selected for hypothesis testing depends on the sample size, study aim and objectives, the population standard deviation and the data type, among other factors. (Uttley, 2019). The choice of hypothesis test also depends on the nature of the dependent variable (Ijeh, 2023; Ranganathan et al., 2017), whether it is categorical or continuous and the specific goal of the analysis. Generally, the z-test, t-test, Chi-Square test, Anova test have proven suitable for testing hypotheses (Kotronoulas et al., 2023; Walker, 2019). The z-test measures the mean of a large sample or population with known variance. T-test can be a one-sample or two-sample t-test. One sample t-test measures the mean of a single group against a known one, while a two-sample t-test compares the means of two independent variables (Emmert-Streib & Dehmer, 2019). The chi-square test examines the relationship between categorical variables, and ANOVA (Analysis of Variance) compares means among three or more variables (Kotronoulas et al., 2023).

Common significance thresholds (α) for hypothesis testing include 0.01, 0.05, and 0.10, with $\alpha = 0.05$ widely accepted across empirical disciplines (Sweeney & Anderson, 2025). In this study, $\alpha = 0.05$ was selected as the decision rule for testing the significance of categorical predictors influencing OSC adoption. This level is consistent with established research practices in construction-related studies (Gamil & Abd Rahman, 2021). It ensures robust inference about which factors are not only relevant but statistically valid for inclusion in the machine learning modelling pipeline, thus bridging inferential statistics with predictive analytics.

Following the recommendation of (Okolie, 2023; Sesay et al., 2021), who have used Chi-Square for hypothesis testing in non-construction related studies with categorical data and (Jin et al., 2022; Lin et al., 2021; Wuni & Shen, 2023) who have vastly used Chi-Square in CEM studies with categorical data, Chi-Square was the preferred testing choice for this study hypothesis because it is well suited for categorical data of this nature.

The p-value of a test has been identified as the critical value or threshold that the test statistic must exceed to reject the null Hypothesis. “The p-value is the probability of obtaining the observed results (or something more extreme), assuming that the Null Hypothesis is true.” (Biau et al., 2010). The p-value is, therefore, the probability of observing the test result under the null hypothesis. The significance of a variable, α , is therefore relatable to p-value in the Chi-Square test used for conducting this hypothesis test. Where the p-value is more than the defined α value, the null hypothesis is rejected; otherwise, it is upheld, and where the p-value is equal to the α value, the null hypothesis has no effect (Fisher, 1992; Goodman, 1999). To this end, the statistical significance of the predictors is set at α value < 0.05 .

Drawing from the findings made from the SLRs and interview analysis, the following null hypothesis were proposed for this study.

6.3.2 Formulating the Hypotheses ($H_{0,1-7}$)

From the SLR, driver themes like Improved Productivity, Improved Environment and Safety and, Construction business and cost management with frequency counts of 140, 95 and 38 respectively (*See Table 2.1*) suggest strong influence on OSC adoption while themes like Government Intervention, and, Supply Chain and Site Management with frequency counts of 9 and 7 respectively suggests low impact on OSC adoption. Barrier themes like Supply Chain

Management, Design and construction technology, Construction Industry Management and OSC Knowledge, Communications and Data Management with counts of 82, 72, 57 and 48 respectively (*See Table 2.2*) suggest high importance to OSC adoption while themes like Attitude, Funding, Policies and Interventions, and Environmental Sustainability with counts of 32, 20, 19 and 9 suggest low impact on OSC adoption.

In a similar vein, the qualitative content analysis factors like Supply Chain Management, Time saving, Productivity and Perception with weights of 13.97%, 11.03%, 10.29% and 9.56% (*See Table 5.3*) all appears to be strongly influencing OSC adoption in the UK while factors such as Attitudes and Awareness, Government Interventions, Education and Training, Improved Health and Safety, and Stakeholders' Influence with weight of 4.41%, 4.41%, 4.41%, 3.68% and 3.68% respectively suggest low influence on OSC adoption in the UK.

Following reviews made at survey questionnaire pre-test stage (*See Section 4.4.7*), the themes were arranged into constructs, and some variables have also been re-distributed under an appropriate constructs (*See Table 6.1*). Therefore, the null hypotheses were postulated by using the factors under each construct to establish and test if there is a relationship between that construct's factor and the dependent variable. At this stage, it does not matter whether the factor is most or least mentioned as the essence of hypothesis testing in this case is to check if a relationship exists between the factor and the dependent variable, and consequently between the construct and the dependent variable.

The following null hypotheses (H_0) and alternative hypothesis (H_a) are put forward:

H_{01} : There is no relationship existing between project attitude construct and OSC adoption in the UK.

H_{a1}: There is relationship existing between project attitude construct and OSC adoption in the UK.

H₀₂: There is no relationship existing between Project Management Team (PMT) construct and OSC adoption in the UK.

H_{a2}: There is relationship existing between Project Management Team (PMT) construct and OSC adoption in the UK.

H₀₃: There is no relationship between Project Knowledge and Data (PKD) construct and OSC adoption in the UK.

H_{a3}: There is relationship between Project Knowledge and Data (PKD) construct and OSC adoption in the UK.

H₀₄: There is no relationship between Perception (PP) construct and the dependent variable.

H_{a4}: There is relationship between Perception (PP) construct and the dependent variable.

H₀₅: There is no relationship between the Design and Construction Factor (DCF) construct and OSC adoption.

H_{a5}: There is relationship between the Design and Construction Factor (DCF) construct and OSC adoption.

H₀₆: There is no relationship between Supply Chain and Logistics (SCL) factor and the dependent variable.

H_{a6}: There is relationship between Supply Chain and Logistics (SCL) factor and OSC adoption.

H₀₇: There is no relationship between Policy, Regulations and Sustainability (PRS) Construct variables and adoption.

H_{a7}: There is relationship between Policy, Regulations and Sustainability (PRS) Construct variables and the dependent variable.

H₀₈: There is no relationship between Construction Market and Cost (CMC) Construct and OSC adoption.

H_{a8}: There is a relationship between Construction Market and Cost (CMC) Construct and OSC adoption.

6.3.3 Hypotheses Testing

Hypothesis testing was done using Chi-square test of independence. Below is the table reporting the variables that show strong relationship with the dependent variable from Chi-square using p-values (statistical significance), and degree of freedom. The test initially returned over forty variables at p-value ≥ 0.05 . This ($>40/103$) was considered too much for criticality test; therefore, the p-value was reduced to 0.01. This returned twenty-four variables.

See Table 6.3 and Figure 6.7

Table 6.3: Variable Significance according to Chi-Square Test

S/No	Variable Name	Variable Tag	Chi2	p-value	Degrees of Freedom
1	Road width that fits truck size	SCL7	56.30235	2.17E-06	16
2	What was/is the OSC project duration?	PD9	44.38146	1.31E-05	12
3	Specialization	GF1	99.77153	7.6E-05	52
4	What client type owned the OSC project?	PD8	29.93785	0.000217	8
5	What type of residential building was/is it?	PD4	43.72853	0.000217	16
6	How long would it have taken the project if OSC was not considered or used?	PD11	43.58575	0.000228	16
7	Scalability (Repeatability of design and project modules)	DCF10	43.29122	0.000253	16

S/No	Variable Name	Variable Tag	Chi2	p-value	Degrees of Freedom
8	What class of building/infrastructure was developed for the project?	PD3	46.06455	0.00079	20
9	How much consideration was given to availability of past OSC Project Data to support adopting OSC for the project?	PKD2	39.72666	0.000853	16
10	What type of Multi-storey building was/is it?	PD5	32.97667	0.000976	12
11	Access Road to the site that fits truck size	SCL8	39.07142	0.001062	16
12	Mortgage Accessibility (with respect to adopting OSC on the project)	CMC15	39.02046	0.00108	16
13	Nature of the construction industry (fragmented and complex)	CMC5	32.02616	0.001371	12
14	Awareness of planning authorities: To what extent was the knowledge level of planning authorities concerning Offsite Construction (OSC) construction methodologies influence their decision to appro...	AW4	37.83939	0.001595	16
15	OSC Building (Construction) material quality (a belief that OSC construction material is not of quality as traditional construction material)	DCF4	36.48896	0.002473	16
16	Availability of construction industry SMEs' support for the OSC project	CMC6	36.20993	0.002705	16
17	OSC Building (Construction) material durability (a belief that OSC construction material is not as durable as traditional construction material)	DCF5	35.60409	0.003283	16
18	Site Hedging (Availability of site storage area for components and modules)	SCL11	35.36727	0.003539	16
19	Design lead time (Is the amount of time required before freezing OSC design quicker or slower)	DCF1	34.76148	0.004284	16

S/No	Variable Name	Variable Tag	Chi2	p-value	Degrees of Freedom
20	Negative historical perception of OSC/prefabricated buildings on the project (the mindset that OSC could fail like it did when it was first used around mid 1900s to resettle war soldiers and their...	PP1	34.35838	0.00486	16
21	Perception of real estate professionals in terms of how end-users, e.g., rentals, may view the use of OSC on the project.	PP7	34.18499	0.00513	16
22	How much consideration was given to availability of communication tools to support adopting OSC for the project?	PKD3	33.93651	0.005541	16
23	Shortage of skilled OSC workers	SCL14	33.64924	0.006056	16
24	Initial setting up cost (1st instalment paid to kick start the project)	CMC9	20.49541	0.008616	8

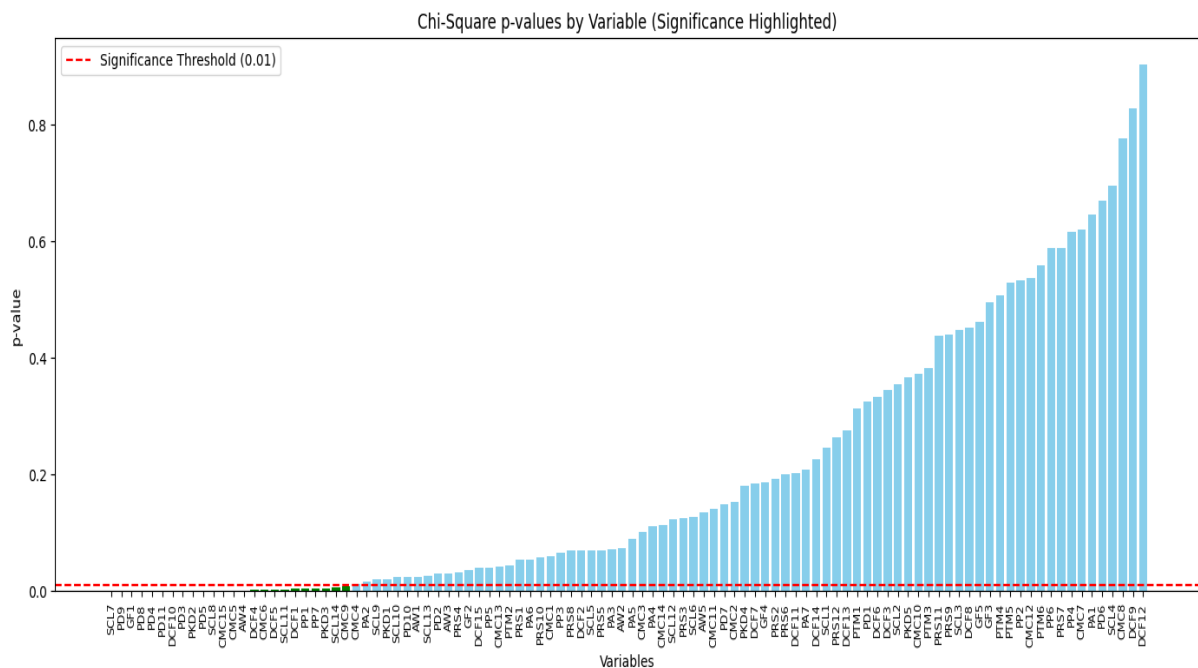


Figure 6.7: Significant variables according to Chi-Square Test

6.3.4 Hypothesis Validation

Following the results from Chi-Square test of independence, twenty-four (24) variables - **AW4, CMC5, CMC6, CMC9, CMC15, DCF1, DCF4, DCF5, DCF10, GF1, PD3, PD4, PD5, PD8, PD9, PD11, PKD2, PKD3, PP1, PP7, SCL7, SCL8, SCL11, and SCL14** - from eight (8) constructs (*Awareness, Construction Management and Cost, Design and Construction Factors, General Information, Project Details, Project Knowledge and Data, Perception, and Supply Chain and Logistics*) demonstrated a significant relationship with the dependent variable. Thus, the postulated null hypotheses (H_0) and (H_α) are discussed below:

H_{01} : There is no relationship existing between awareness construct (AW) variables and the dependent variable.

Going by the outcome of the Chi-square test, one of the Awareness construct variables (AW4) showed a relationship with the dependent variable. Thus, the null hypothesis (H_{01}) is rejected.

H_{02} : There is no relationship existing between the Project Management Team (PMT) construct variables and the dependent variable.

From the Chi-square test results, no Project Management Team variables (PTM) displayed a significant relationship with the dependent variable. Thus, the null hypothesis (H_{02}) is upheld.

H_{03} : There is no relationship between Project Knowledge and Data (PKD) construct variables and the dependent variable.

Going by the outcome of the Chi-square test, two variables from Project Knowledge and Data construct (PKD2 and 3) showed significant relationship with the dependent variable. Thus, the null hypothesis (H_0) is upheld.

H_{04} : There is no relationship between Perception (PP) construct variables and the dependent variable.

Drawing from the p-values of the test, two (2) variables from OSC Perception (PP), **PP1** (p-value 0.00486), and **PP7** (p-value 0.00513) showed strong significant relationship with the dependent variable (DVMain). Thus, there is a relationship between PP construct and DVMain and the null hypothesis (H_0) is rejected.

H_{05} : There is no relationship between the Design and Construction Factor (DCF) construct variables and the dependent variable.

Going by the Chi-square test result, four variables from Design and Construction Factor construct (DCF1, 4, 5 & 10) showed a significant relationship with the dependent variable. Thus, the null hypothesis (H_{05}) is rejected.

H_{06} : There is no relationship between Supply Chain and Logistics (SCL) Construct variables and the dependent variable.

Drawing from the p-values of the test, four variables from the Supply Chain and Logistics (SCL) construct, **SCL7, 8, 11 and 14** showed strong significant relationships with the dependent variable (DVMain). Thus, there is a relationship between SCL construct and DVMain and the null hypothesis (H_{06}) is rejected.

H₀₇: There is no relationship between Policy, Regulations and Sustainability (PRS) Construct variables and the dependent variable.

Going by the outcome of the ordinal logistics regression, no variable from Policy, Regulations and Sustainability construct showed any significant relationship with the dependent variable. Thus, the null hypothesis (H₀₇) is accepted.

H₀₈: There is no relationship between Construction Market and Cost (CMC) Construct variables and the dependent variable.

Drawing from the p-values of the hypothesis test, four (4) variables from Construction Market and Cost construct (CMC 5, 6, 9 & 15) showed a strong significant relationship with the dependent variable (DVMain). Thus, there is a relationship between CMC construct and DVMain and the null hypothesis (H₀₈) is rejected.

Following identified associations of the influencing factors on OSC adoption from hypothesis testing, the data was further wrangled for determining which variables may be contributing equal (multicollinearity) effect to OSC adoption in the UK before employing rigorous feature selection approach to determine the critical ones and Machine Learning model development to identify the best predictive model.

CHAPTER 7: ESTABLISHING THE MOST CRITICAL FACTORS THROUGH FEATURE SELECTION APPROACH

Chapter Overview

In this chapter, correlation analysis was used to address multi-collinearity following the pre-processing and transformation conducted on the dataset collected before proceeding to feature selection. It first used multi-class classification and then binary classification for both mode and KNN missing data imputation methods. Variables (factors) causing noise in each experiment case were dropped and the selected variables from the pre-processed data in each experiment were analysed to identify the critical factors influencing OSC adoption using. Ten (10) feature selection algorithms, common to classification tasks, were used for the analyses. The most critical factors were extracted by comparing and identifying the factors present in all cases of the experiments.

7.1 Correlation Analysis

From the exploratory analysis, it emerged that majority of the data features are not normally distributed (*See Figures 6.4(a-d) and 6.5*). Some of the improvements made to the cleaned data are feature scaling- standardisation (using MinMax scalar). Data scaling, a type of standardisation was used for converting the data to normal distribution (Han et al., 2011) and for bringing the data within the same range using scale (Muhammad Ali & Faraj, 2014), thus, reducing dispersion on the data. The cleaned (processed) data was further explored for relationships among the features (factors/variables) before identifying the critical ones.

Prior to feature selection (FS) and feature engineering (FE), correlation analysis was done using Spearman correlation because the data is non-Gaussian (non-normal distribution) and it is also

ordinal (Berrar, 2018; Fushiki, 2011). The correlation analysis was first visualised on a heatmap before being expressed using a Dendrogram. (*See Figures 7.1a and 7.1b*).

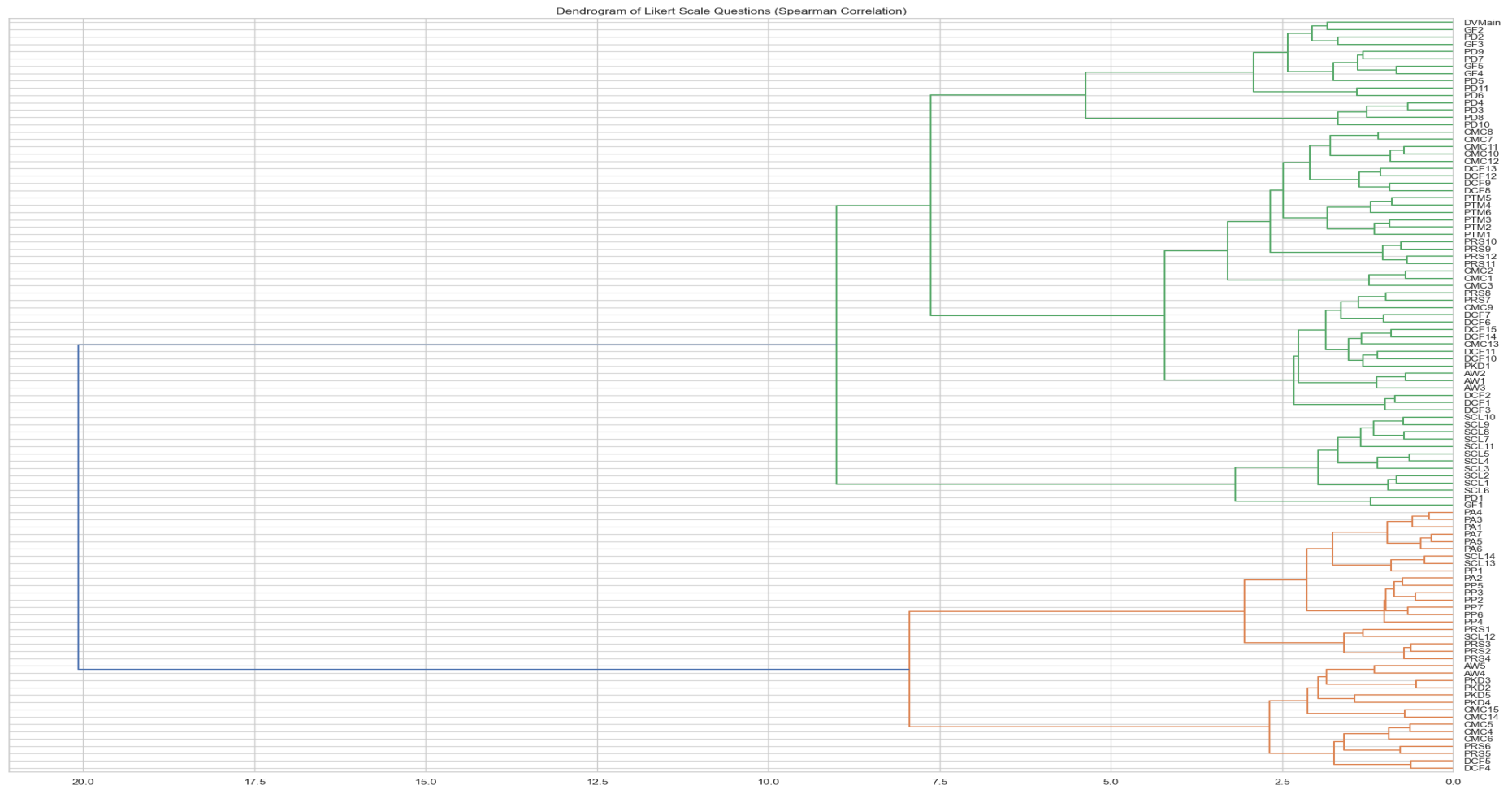


Figure 7.1b: Visualisation of Correlation Analysis Dendrogram (The Mode Imputation Instance for Multi-Class Classification)

From the correlation analysis, a few factors were highly correlated, suggesting limited redundancy and strong grouping among the factors examined (Field, 2009). This implies minimal noise (multi-collinearity) within the dataset and that more individual items (factors) were relevant to the target variable (DVM_{main}), which is good for feature diversity in machine learning (ML) and predictive validity (Hair et al., 2013).

To address the multi-collinearity in the dataset and eliminate the feature causing noise within the data, the correlation threshold was set to 0.7 (Dormann et al., 2013). This is because while numerous features may influence a process, not all are critical to the process's success (Daget & Zhang, 2019; Wuni et al., 2022). Since the features that correlate at 0.7 and above are contributing the same effect to the data according to Hair et al., (2013), one of such was selected arbitrarily. Arbitrarily selecting a feature in a highly correlated pair is a practical necessity when addressing multi-collinearity and this has been used in various empirical studies and statistics workflows (O'brien, 2007), including construction-related studies (Wusu et al., 2022). Arbitrarily selecting a feature over another does not undermine the information content of the dataset (Dormann et al., 2013). **Table 7.1** provide the feature that correlated at ≥ 0.7 and those dropped.

Table 7.1: Dropped Features and Retained Features (A case of Multi-Class Classification using Mode Imputation)

S/No	Dropped Features	Kept Features	Correlation Value
1.	PP3	PP2	0.771
2.	DCF5	DCF4	0.728
3.	PRS4	PRS3	0.706
4.	CMC5	CMC4	0.714
5.	SCL14	SCL13	0.815
6.	CMC2	CMC1	0.761
7.	PKD3	PKD2	0.701
8.	PA2	PA1	0.712
9.	PD4	PD3	0.853
10	PA7	PA6	0.880

NB: See *Appendix 10* for details of other approaches.

The correlation analysis was executed using a python data analysis code. Details of the features that emerged after handling multi-collinearity for multi-class classification (MCC) and binary classification (BC) using Mode and KNN missing data imputation are presented in **Table 7.2**. Ninety-two (92) features emerged from Mode imputation, (Under Multi-Class), Mode and KNN imputations (under binary classification) while ninety-three (93) features emerged from KNN imputation (Under Multi-Class), for further analysis. Following the poor results initially observed from the first set of experiment using MCC, **Table 7.2** reports the variable (features) from the correlation exercise for Multi-Class Classification (MCC) and Binary Classification (BC) using both Mode and KNN missing data imputations.

NB: Experimenting with MCC (mode and KNN missing data imputation) and BC (mode and KNN missing data imputation) was because upon developing the ML models, poor results were observed for MCC when tried with both mode and KNN missing data imputation (See Section 8.1).

Table 7.2: Selected Features after Handling Multicollinearity

S/No	Multi Class Classification (MCC)		Binary Classification (BC)	
	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)
1	SCL3	CMC10	DCF12	DCF8
2	CMC8	CMC13	PD7	CMC14
3	DCF9	PRS9	DCF14	SCL5
4	SCL8	CMC3	AW1	PA6
5	PD3	PD5	CMC9	PD5
6	PKD1	PKD4	DCF1	DCF6
7	CMC6	SCL7	CMC11	PP1
8	DCF14	SCL4	PD10	PTM6
9	PA5	PRS3	SCL7	SCL4
10	AW4	PRS1	SCL4	SCL12

S/No	Multi Class Classification (MCC)		Binary Classification (BC)	
	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)
11	PP5	PA4	GF5	GF1
12	PKD2	DCF1	SCL8	SCL9
13	PD7	PKD5	AW4	PKD5
14	DCF6	CMC14	GF3	PKD2
15	PA1	CMC6	PKD5	CMC15
16	PTM5	DCF13	PRS10	SCL8
17	SCL6	DCF15	PRS7	PRS6
18	PRS1	PTM2	PD3	GF5
19	GF5	AW3	SCL2	PRS12
20	CMC13	PA6	SCL5	CMC7
21	PP7	AW4	SCL3	PD8
22	SCL2	PTM4	AW5	GF3
23	SCL13	PP7	PP7	PD1
24	DCF15	SCL11	PD1	PRS3
25	PRS8	PKD1	PP4	PP2
26	DCF3	CMC4	AW2	AW4
27	CMC1	DCF10	PP5	SCL3
28	SCL12	DCF6	DCF3	PRS2
29	CMC9	GF2	DCF8	PD7
30	DCF8	CMC1	PKD1	CMC10
31	PRS12	SCL9	DCF11	SCL2
32	PRS3	GF5	SCL10	AW5
33	SCL7	CMC7	PRS6	GF2
34	CMC10	GF4	PRS12	DCF12
35	PRS10	PD2	PD2	DCF4
36	DCF10	PD1	SCL9	PRS8
37	PRS11	AW5	PTM5	DCF2
38	DCF11	SCL13	PA4	CMC13
39	PTM1	GF3	SCL11	PRS1
40	AW2	DCF4	PP6	PD11
41	PTM4	PRS2	DCF13	CMC6
42	DCF4	AW2	PTM1	PKD1
43	SCL9	PA3	PRS11	PRS5
44	PP4	PKD3	CMC3	SCL6
45	GF4	PRS8	SCL13	SCL1

S/No	Multi Class Classification (MCC)		Binary Classification (BC)	
	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)
46	SCL11	PRS12	SCL6	GF4
47	DCF12	CMC11	PD8	PRS7
48	PRS9	PP1	DCF15	CMC9
49	PKD5	PD7	PA1	DCF7
50	SCL5	SCL3	DCF6	PRS10
51	PA4	PTM3	CMC1	PP4
52	PTM3	PA1	DCF10	DCF1
53	GF2	PA5	PTM3	AW3
54	DCF7	SCL12	PP1	PTM4
55	GF1	PRS5	GF2	CMC8
56	AW1	DCF9	PA6	PTM5
57	GF3	PTM6	CMC6	AW1
58	PD2	DCF2	PD9	SCL7
59	CMC15	CMC12	SCL12	PTM1
60	PRS6	DCF3	PKD4	PKD4
61	DCF1	DCF11	PRS5	DCF13
62	SCL4	PD9	CMC12	CMC11
63	PP1	PD11	PTM6	PD6
64	DCF13	SCL5	PRS1	SCL10
65	SCL1	PP5	DCF7	DCF10
66	PA6	SCL10	GF4	AW2
67	PRS2	PKD2	CMC8	PD2
68	PTM2	PP6	DCF9	DCF9
69	PP2	PD8	PD5	PP6
70	CMC4	PRS7	CMC7	PRS11
71	AW3	DCF8	AW3	DCF3
72	PRS5	AW1	CMC10	PD9
73	PD10	DCF14	GF1	CMC12
74	PD9	SCL2	CMC14	DCF11
75	CMC3	PP4	PD6	PA1
76	AW5	SCL6	PRS3	PA5
77	PD8	PTM1	PTM2	PTM3
78	CMC14	PP2	PA5	PRS9
79	DCF2	PRS11	PD11	CMC3
80	SCL10	PTM5	PA3	CMC1

S/No	Multi Class Classification (MCC)		Binary Classification (BC)	
	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)	Selected Variable (Mode Imputation)	Selected Variable (KNN Imputation)
81	CMC12	PD10	CMC4	CMC4
82	PA3	CMC9	PTM4	PP5
83	PTM6	CMC8	PRS9	DCF15
84	PD1	GF1	PP2	PTM2
85	CMC11	SCL1	DCF4	SCL11
86	PRS7	PRS6	PKD2	PP7
87	PKD4	DCF7	SCL1	PA3
88	PD6	PD3	PRS2	PD10
89	PD5	SCL8	DCF2	PA4
90	PD11	DCF12	CMC15	SCL13
91	CMC7	PD6	PRS8	DCF14
92	PP6	CMC15	CMC13	PD3
93		PRS10		
	DVMain	DVMain	DVMain	DVMain

New sample datasets, from the original dataset, emerged from each of the missing data imputation described. The analysis thus has four (4) new datasets to work with from this point, namely MCC (Mode Imputation), MCC (KNN Imputation), BC (Mode Imputation), and BC (KNN Imputation). The new sample datasets from correlation analysis were pre-processed using standardisation before conducting FS and establishing the most critical features influencing wider OSC adoption in the UK.

Considering that the number of features selected after handling multi-collinearity are still much for each missing data imputation method, FS was used to select the most relevant ones to DVMain (*See Section 7.2*) before comparing and establishing the most critical factors. Additionally, the lists of features in each FS experiment were used to create more sample

datasets for model development. (*See Figure 7.2 and Section 7.2*). *Figure 7.2* provides an architecture of the steps taken to establish the critical OSC influencing factors.

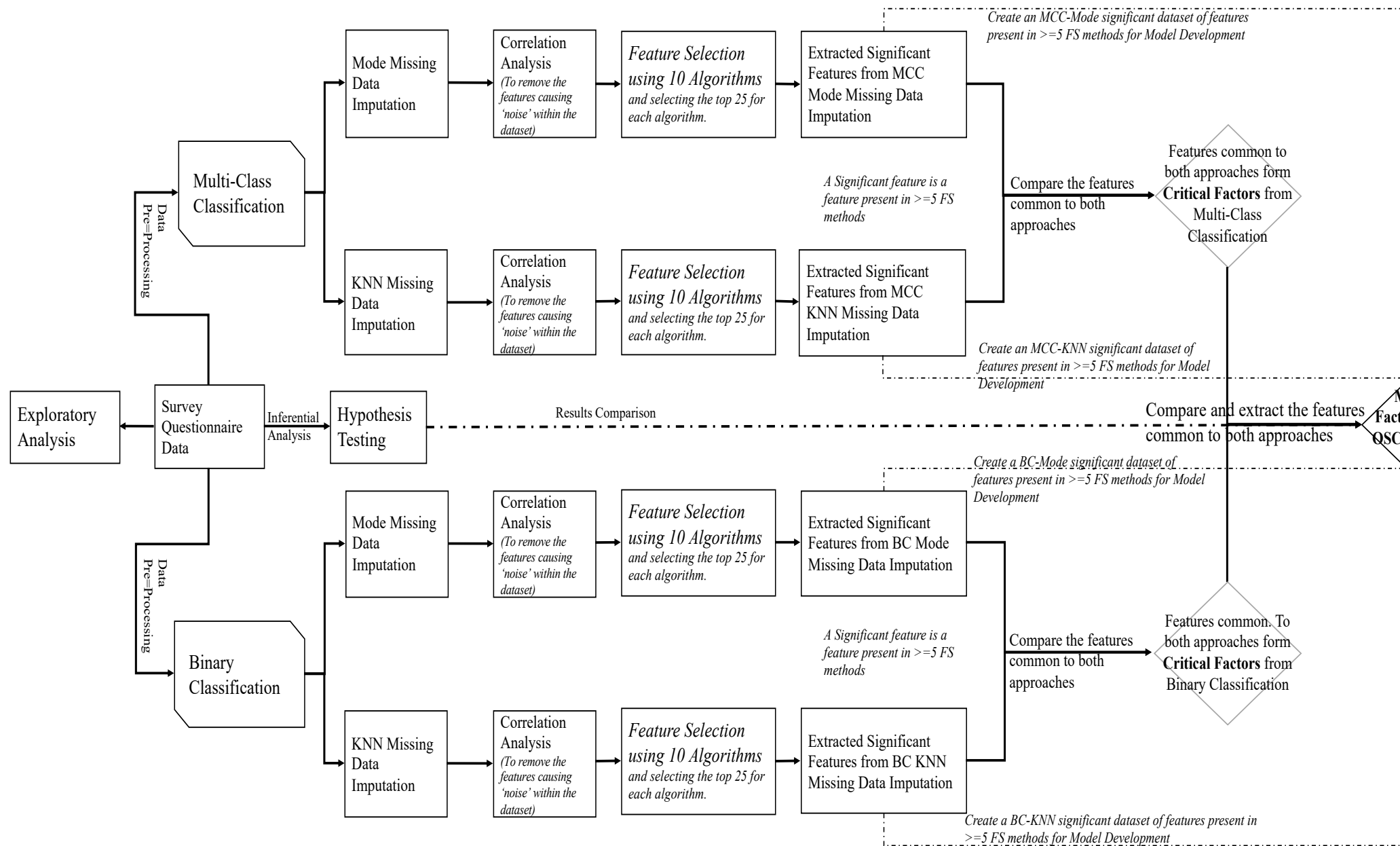


Figure 7.2: Quantitative Analysis/ Feature Selection Framework

To put context to understanding the terminology interchanges, the word ‘variables’ was used in the questionnaire analysis for the factors developed from interview analysis. Also, the word ‘variables’ was transformed to features in Machine Learning. The word ‘features’ appears more commonly used in the computing world while both ‘variable’ and ‘features’ are used in non-computing engagements. Since this phase of the study is more related to computer sciences, this transformation was necessary to ensure the appropriate word/term was used within the analysis as fitting the computing context as the words features and variable are more used in the machine learning world. For example, (though subjective), while it is common to say feature/variable selection, feature engineering is more common than variable engineering, even though they imply same thing.

7.2 Feature Selection.

To establish the most significant variables favouring wider OSC adoption in line with the goal of this study and to improve the model development reliability (Guyon & Elisseeff, 2003), the study employed rigorous feature selection methods. This approach has been employed in different construction related studies (Balogun et al., 2021; Egwim et al., 2021; Olu-Ajayi et al., 2023a; Wusu et al., 2022). This was necessary because the number of independent features after handling multi-collinearity (92, 93, 92 and 92, *See Table 7.1*) still appear large and could cause high dimensionality curse issues in the model development (Verleysen & François, 2005), hence, the rigorous FS approach to streamline the number of features.

Feature selection (FS) method is the process of aggregating the best subset of features that are contributing meaningfully to a study’s purpose and can improve model performance using various proven algorithms (Guyon & Elisseeff, 2003). It is the process of identifying and selecting a subset of relevant features from the dataset that contribute most to the predictive

output of a model, thereby reducing overfitting, improving model performance and decreasing computational cost (Chandrashekar & Sahin, 2014).

In selecting the features that most influence the adoption of OSC, ten (10) common feature selection models, fitting for categorical data and classification exercise were employed (Ijeh, 2023). The considered FS methods for this exercise, in line with the dataset characteristics and research aim, are Chi-Square (with One-hot encoding), Analysis of Variance (ANOVA), Ordinal Logistics Regression with Recursive Feature Elimination (OLR), Recursive Feature Elimination with Logistics Regression (RFE), Lasso (with One-Hot Encoding), Permutation Importance features, XGBoost Importance, Spearman Correlation Features, Mutual Information Features, and Information Gain Features. These are some of the most common models for classification exercises that that fit a categorical data. Leveraging the consensus across multiple FS methods help identify robust predictors and stabilise feature selection, especially in high-dimensional datasets (Saeys et al., 2007).

7.2.1 Feature Selection Models Used in this study.

Chi-Square (with One-hot encoding): It is a filter-based feature selection method that measures the statistical dependence between categorical independent variables and a categorical target variable (Liu & Motoda, 2007). It evaluates whether the observed frequency distribution of a feature is significantly different from an expected distribution. It converts categorical variables to numerical using one-hot encoding and computes the Chi-Square statistics for each feature and target variable. It selects features with the highest Chi-square scores (smaller p-values). It is particularly useful when both independent features and dependent target variable are categorical (Forman, 2003).

Analysis of Variance (ANOVA): It is a filter based method that uses F-test to measure how much variance each independent feature contributes to separating target classes. It assumes the features are continuous and the target is categorical, making it ideal for classification tasks where statistical differences in means are relevant (Berrar, 2018).

Ordinal Logistics Regression with Recursive Feature Elimination (OLR-RFE): A hybrid wrapper/embedded FS method that combines recursive feature elimination method (RFE) to iteratively remove least important feature and uses ordinal logistics regression to (OLR) to predict ordered categories (Sesay et al., 2021). It works on data with ordinal target variables (ordered categories) and when features are either categorical (encoded) or continuous (Rifada et al., 2023). It trains an ordinal logistics regression model, rank the features based on their statistical significance and iteratively remove the weakest feature until optimal performance is achieved (Faisal et al., 2020).

Recursive Feature Elimination with Logistics Regression (RFE): it is a wrapper-based FS method that uses logistics regression as the base model to iteratively remove least significant features. It works well for binary and multi-class classification (Guyon et al., 2002). It is suitable for datasets that contain both categorical and numerical features and datasets with binary or multi-class categorical target variables (Guyon et al., 2002; Kuhn & Johnson, 2013).

Lasso (with One-Hot Encoding): Also known as L1 regularisation, it adds a penalty to the absolute value of coefficients, shrinks feature weights to zero and effectively selects only the most important features (Ng, 2004). It works well for high-dimensional categorical datasets, datasets containing highly correlated features and when feature selection and regularisation are needed simultaneously. It converts categorical features using one-hot encoding, fits a lasso

regression model and selects features with non-zero coefficients (Tibshirani, 1996; Zou & Hastie, 2005).

Permutation Importance features: it is a model agnostic wrapper-based FS method that evaluates feature importance by randomly shuffling each feature and measuring its impact on model accuracy by training the model on a dataset, shuffling one feature randomly, measuring how much model accuracy decreases and it identifies the features causing the largest drop in accuracy (Breiman, 2001). It is useful for non-linear models (tree-based and deep learning), imbalanced dataset and when a model-agnostic feature is required (Altmann et al., 2010).

XGBoost Importance: It is an embedded tree-based FS method that uses XGBoost built-in feature importance score for selecting significant features. It trains an XGBoost model, extracts the scores of important features and selects the features with the highest scores (Lundberg & Lee, 2017). It is useful for datasets with categorical and numerical features and also for imbalance dataset (T. Chen & Guestrin, 2016).

Spearman Correlation Features: It is a filter FS method that measures the monotonic relationship between ordinal categorical features and dependent features. It is applicable when dealing with variables with ordered categorical values and datasets with non-linear but monotonic relationships (Mukaka, 2012).

Mutual Information Features: It is a filter FS method that measures how much the knowledge of one variable reduces uncertainty about another variable. It works well on categorical or mixed datasets or datasets with non-linear relationships (Peng et al., 2005).

Information Gain Features: It is a decision tree-based FS method that finds features with the highest information gain to the target variable (Quinlan, 1986). It is useful in classification problems and identifies features that contribute most to class separation (G. Brown et al., 2012).

FS methods can be filter, wrapper or embedded (Saeys et al., 2007). They can also be statistical, model-dependent or tree-based types (Li et al., 2016). Filter methods are fast and scalable but may ignore feature interactions (Dash & Liu, 1997). They are very efficient for high-dimensional datasets (Dash & Liu, 1997). The wrapper methods are model-dependent and usually computationally expensive. They are very efficient when feature interaction is required (Kohavi & John, 1997). The embedded categories have in-built feature selection engines for training and are highly efficient for non-linear datasets (Hastie et al., 2009; Ng, 2004). These methods balance efficiency and feature selection but require hyperparameter tuning. **Table 7.3** gives a summary of the ten FS models.

Table 7.3: Feature Selection (FS) Method Categorization

Feature Selection Method	Category	Type
Chi-Square Test (With One-Hot Encoding)	Filter	Statistical, Independence Test
Analysis of Variance (ANOVA F-Test)	Filter	Statistical, Variance Analysis
Ordinal Logistic Regression with Recursive Feature Elimination (OLR-RFE)	Wrapper/ Embedded	Classification-based, Handles Ordinal
Recursive Feature Elimination with Logistic Regression (RFE-LR)	Wrapper	Model-dependent
Lasso (With One-Hot Encoding)	Embedded/ Regularization	L1 Regularization, Model-based Selection
Permutation Feature Importance	Wrapper/ Model-agnostic	Model-agnostic, Randomized Importance
XGBoost Feature Importance	Embedded/ Tree-based	Tree-based
Spearman Correlation Features	Filter	Statistical, Correlation
Mutual Information Features	Filter	Statistical, Information Gain
Information Gain Features	Filter	Statistical, Decision Trees-Based

7.2.2 Extracting the Critical Factors.

The top 25 features (variables) for each FS method were extracted and noted. Selecting top n features is a common strategy in ML exercise to reduce high dimensionality while maintaining model interpretability (Guyon et al., 2002; Guyon & Elisseeff, 2003). From the top 25 features extracted from each FS method, features that appear in 5 or more ($\geq 50\%$) FS methods across the 10 FS methods were collated and named **Significant Features**. Using $\geq 50\%$ criteria is in line with an average pass mark for basic studies (StudyIn, 2023). The approach has been used in some construction related studies (Balogun et al., 2025). **Table 7.5** gives a summary of the top 25 selected features for MCC (Mode missing data imputation), highlighting those present in five or more FS methods. Therefore, this study went ahead with four new sample datasets, namely MCC (Mode Imputation), MCC (KNN Imputation), BC (Mode Imputation), and BC (KNN Imputation) significant datasets. See **Appendix 11** for FS Tables for other approaches.

NB: Items in Table 7.5 with the same colour highlights their recurrence in more than 5 FS model

Table 7.5: Top 25 features selected from each FS Method (A case of MCC using Mode missing data imputation)

S/N o	Chi-Square (One-Hot)	ANOVA Features	Ordinal Regression	Logistic	RFE Features	Lasso (One-Hot)	Permutation Importance	XGBoost Importance	Spearman Correlation	Mutual Information	Information Gain
1	AW2	AW4	PP5		AW4	PRS8	DCF12	PD11	AW4	AW2	GF2
2	AW4	CMC15	DCF11		CMC6	AW4	DCF13	PD8	PD9	CMC14	PD9
3	CMC15	CMC4	PTM1		CMC7	CMC15	DCF14	PD5	SCL8	CMC3	SCL7
4	CMC6	CMC6	SCL8		CMC8	PP7	PD10	PD3	SCL7	CMC7	SCL12
5	CMC9	CMC9	PTM4		CMC9	SCL10	PD1	PD6	CMC4	DCF1	PD8
6	DCF1	DCF1	GF2		DCF10	PD3	PA6	SCL8	PKD2	DCF10	GF1
7	DCF10	DCF10	CMC13		DCF11	PP5	PA5	PA6	PP5	DCF11	CMC15
8	GF1	DCF15	AW4		DCF4	PP1	PA4	AW2	SCL10	DCF2	PKD2
9	PD11	DCF4	PRS8		PA1	DCF10	PA3	SCL11	PD3	DCF3	PP7
10	PD3	PD11	DCF8		PA4	SCL8	PA1	AW4	DCF10	DCF7	PTM2
11	PD5	PD3	DCF12		PA5		GF5	PRS1	DCF15	GF1	PRS6
12	PD9	PD5	SCL13		PA6		GF4	SCL7	PRS8	GF5	DCF4
13	PKD2	PD8	PD6		PD11		SCL8	CMC10	SCL11	PA3	CMC6
14	PP1	PD9	PD9		PD8		GF3	PTM3	CMC6	PA5	DCF10
15	PP5	PKD2	DCF15		PKD1		GF1	CMC9	DCF1	PD10	SCL9
16	PP7	PP5	PA4		PKD2		DCF9	CMC15	CMC13	PD8	GF4
17	PRS1	PRS3	PRS1		PKD4		DCF8	PD7	AW1	PD9	PRS2
18	SCL11	SCL10			PP5		DCF7	SCL12	PD11	PKD2	PRS10
19	SCL7	SCL11			PRS8		DCF6	CMC8	PRS6	PP7	PD11
20	SCL8	SCL13			PTM1		DCF4	DCF1	CMC1	PRS12	SCL13
21		SCL5			PTM6		DCF3	PTM1	CMC9	PRS2	PTM5
22		SCL6			SCL10		DCF2	PKD2	CMC15	PRS8	DCF6
23		SCL7			SCL5		DCF15	PP4	GF5	PTM3	DCF3
24		SCL8			SCL8		GF2	CMC6	PRS3	SCL11	PP1
25		SCL9			SCL9		SCL9	PTM2	AW3	SCL7	CMC7

The Significant Feature lists were used for evaluating the critical feature influencing OSC adoption. In each case, features extracted were tabulated before establishing the most critical ones. For instance, in MCC experimentation using Mode missing data imputation, spearman correlation, and the 10 FS methods, a total of sixteen (16) features (factors) were significant (appeared in 5 or more FS methods). The process was repeated for KNN missing data imputation and for binary classification (mode and KNN missing data imputations). (*See Table 7.5 and 7.6 details of the datasets and experiment results*). The significant features were used to establish the most critical factors influencing OSC adoption in the UK and their datasets were used for model development.

Table 7.5: Multi-Class Classification Feature Selection List

Mode Imputation		KNN Imputation		Critical Factors from MCC
Significant Features (Features present in 5 or more FS methods from the 10 FS methods)		Significant Features (Features present in 5 or more FS methods from the 10 FS methods)		Factors Common to both approaches
Feature	Count	Feature	Count	
SCL8	8	SCL8	8	AW4
PKD2	7	SCL7	7	CMC6
DCF10	7	PKD2	7	CMC9
AW4	7	PD11	7	CMC15
PP5	6	AW4	7	DCF1
SCL7	6	PD9	7	DCF10
PD11	6	SCL11	6	PD3
CMC15	6	CMC9	6	PD8
CMC6	6	PKD3	6	PD9
PD9	6	DCF10	6	PD11
PD3	5	CMC6	6	PKD2
DCF1	5	CMC15	6	PP5
SCL11	5	DCF1	6	PRS8
PD8	5	PD8	5	SCL7
PRS8	5	PD3	5	SCL8
CMC9	5	SCL9	5	SCL11
		PP5	5	
16 factors		17 factors		16 factors

*NB: The features in bold are the ones common to both mode and KNN missing data imputation method and are the **Critical factors** from Multi-Class Classification.*

Table 7.6: Binary Classification Feature Selection List

Mode Imputation		KNN Imputation		Critical Factors from BC
Significant Binary Features (Features present in 5 or more FS methods from the 10 FS methods)		Significant Binary Features (Features present in 5 or more FS methods from the 10 FS methods)		Factors Common to both approaches
Feature	Count	Feature	Count	
PP5	10	SCL7	10	AW4
SCL10	9	SCL10	9	DCF1
SCL7	9	PP5	9	DCF4
AW4	8	SCL8	9	DCF10
SCL8	8	PKD2	8	PKD2
DCF10	6	AW4	7	PP5
PKD2	6	DCF4	7	SCL7
SCL11	6	DCF1	7	SCL8
DCF4	6	DCF10	6	SCL10
DCF1	6	SCL11	6	SCL11
PRS6	5	PA5	5	
PD2	5	DCF8	5	
AW3	5	PKD4	5	
CMC6	5			
SCL5	5			
DCF3	5			
16 factors		13 factors		10 factors

*The features in bold are the ones common to both mode and KNN missing data imputation method and are the **Critical factors** from Binary Classification.*

Summarily from the feature selection exercise, the Critical factors from Multi-Class Classification are **AW4**, CMC6, CMC9, CMC15, **DCF1**, **DCF10**, PD3, PD8, PD9, PD11, **PKD2**, **PP5**, PRS8, **SCL7**, **SCL8**, **SCL11** (16 Factors, 7 Constructs) while the critical factors from Binary Classification are **AW4**, **DCF1**, DCF4, **DCF10**, **PKD2**, **PP5**, **SCL7**, **SCL8**, SCL10, **SCL11** (10 Factors, 5 Constructs). Factors common to both approaches, which are the ones considered as most critical to OSC adoption in the UK are **AW4**, **DCF1**, **DCF10**, **PKD2**, **PP5**, **SCL7**, **SCL8** and **SCL11** (**8 Factors**) from five (5) constructs, namely

Awareness, Design and Construction Factors, Project knowledge and Data, Perception, Supply Chain and Logistics.

This outcome fulfils objective four of the study which is to identify and establish the most critical factors influencing OSC adoption in the UK through quantitative analysis and rigorous feature selection techniques

CHAPTER 8: DEVELOPING OSC ADOPTION PREDICTION MODEL

Chapter Overview

The critical factors identified from the feature selection informed new sample datasets for each case of the experiment. Each dataset (obtained after handling multi-collinearity for binary and multi-class approaches) was processed for Machine Learning application. The datasets were split into ratios 80:20 and 70:15:15; and iterated through nine (9) random states. These were evaluated and used to develop predictive models. The models were appraised for best prediction possibility using accuracy and AUC measures before selecting the best.

8.1 Data Preparation for ML Development.

Upon cleaning, pre-processing the data and dropping features with multi-collinearity effect in the initial data, necessary libraries, tools and models were installed or imported as required in Python environment to execute establishing the most critical features using ten (10) feature selection (FS) algorithms suitable for categorical data from commonly reported ones. Data of the features after handling multi-collinearity were further pre-processed for FS and ML model development.

The datasets have one dependent variable, **DVMain** while other variables are the independent ones. Given the multi-class characteristics of the original data (DVMain having five classes), multi-class classification was first used for model development, combining various experiments (*such as Mode and KNN missing data imputation and random state iterations*) in a bid to achieve satisfactory performance and accuracy. Steps taken included data standardisation for both Mode and KNN missing data imputation sample datasets.

Following data pre-processing, the dataset was first split ratio 80:20 and then 70:15:15 when no impressive accuracy emerged from split ratio 80:20 (*See Section 8.4.1*). To ensure all classes were duly represented during the splitting and also to ensure a consistent splitting ratio across the folds, stratified K-fold cross validation, where $K=5$, was introduced during feature engineering to the training data sets alone. Further, the experiments were tuned by iterating the random state of the models using nine (9) values [42, 45, 50, 55, 60, 65, 70, 75 and 80] until some changes was observed in the accuracy result. No improvements were observed when values below 42 were tried.

When no impressive overall performance was observed from the accuracy of multi-class approach-*with best accuracies barely above 50% and only one model having 58.33%*, the dependent variable was coded into a binary format having two classes (Class 1, 1-60 % and class 2, 61-100%), using upper pass limits and lower pass limits idea (Kotsiantis et al., 2005, 2006). This approach also reduced the imbalance gap in DVMain classes (Kotsiantis, 2007). The entire process of Mode, then KNN missing data imputation, applying stratified k-fold cross-validation data splitting into ratios 80:20 and 70:15:15 and random state iteration, were repeated for binary approach. The models were tuned by experimenting with the hyperparameter values to achieve optimal performance using grid search, and the weights of the models with best parameters were saved in-memory.

This rigorous evaluation approach ensures potential overfitting is minimal and that models perform well on unseen or new data. The iterations between training, (validation) and testing improved the model's accuracy and robustness. *See Figure 8.1.*

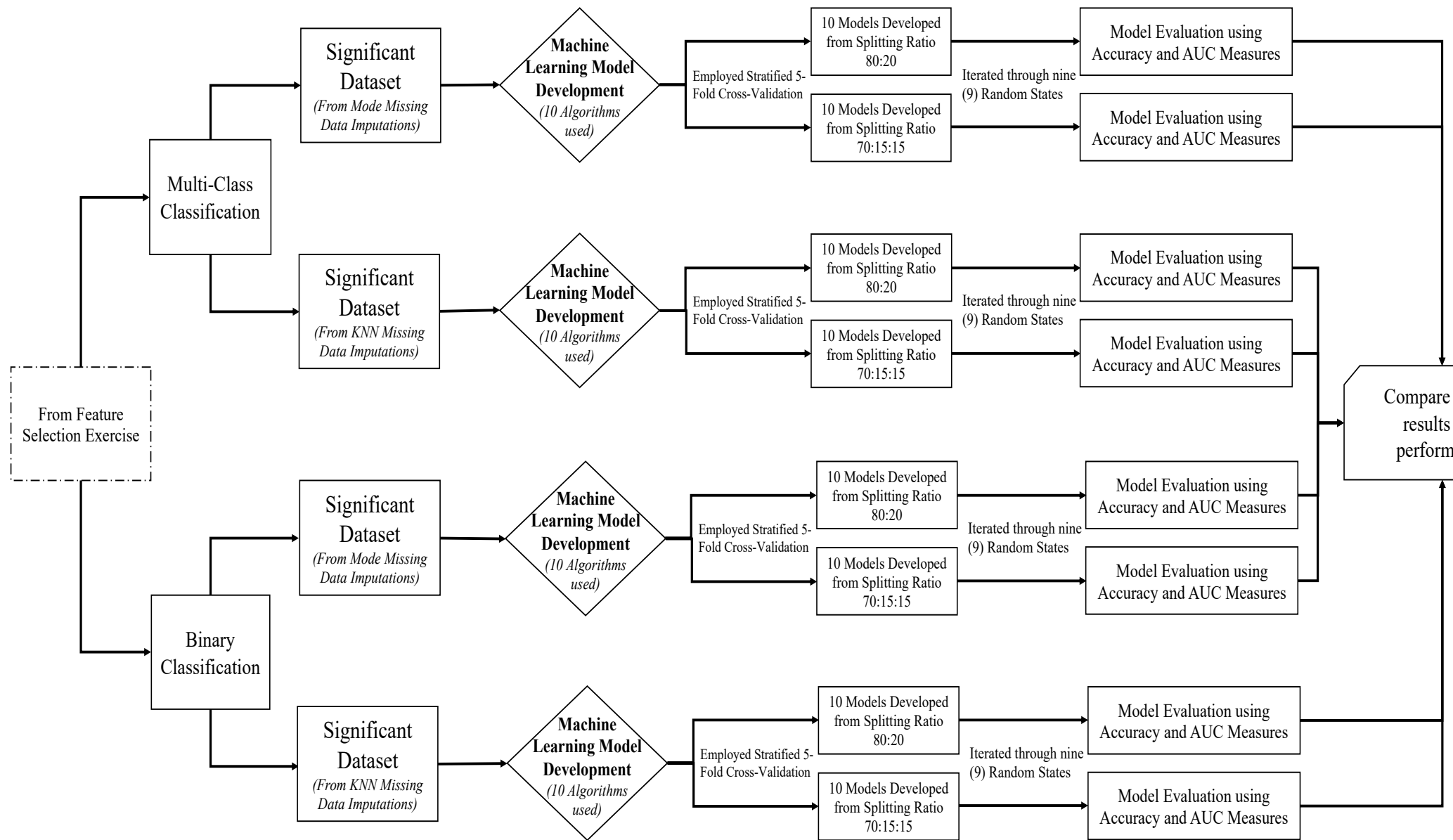


Figure 8.1: Model Development Architecture

To further improve the quality of data used for ML application, Min-Max Scalar was adopted for scaling and standardising the dataset pre-processing phase for model development (Han et al., 2012a). This was preferred to other common standardisation scalars owing to the non-normal distribution nature of the individual features in the dataset (Kotsiantis et al., 2006). An example of such common scalar is Z-score scaling used when the features follow a normal distribution (Juszczak et al., 2002). Unlike standard scaling which centres around the mean and may work best when Gaussian distribution exists, MinMax scaling typically transforms data into a fixed range (usually 0 and 1), making it more suitable for skewed or bounded data distribution (Scikit-Learning, 2024; Sola & Sevilla, 1997). Although both normalisation and standardisation are essential pre-processing techniques, standardising with techniques such as MinMax Scaling, is particularly ideal when the distribution is non-Gaussian and features need to be scaled proportionally (Patro & Sahu, 2015).

In enhancing the features used for model development, the pre-processed data for this study was further processed to ensure it conforms with ML approach through feature engineering, and feature selection.

8.2 Feature Engineering.

Feature engineering is the process of transforming raw data into meaningful features that improve model performance. It involves creating, modifying or changing raw data. It employs domain knowledge (Daget & Zhang, 2019) and mathematical/statistical transformations to achieve this (Zheng & Casari, 2018).

A couple of experiments addressed missing data imputations (using Mode and KNN imputations). *See Section 6.2.1.* Spearman correlation was used to address multi-collinearity.

Correlation among the data variables, (including with DVMain) was viewed using heatmaps and dendrogram charts. The ‘noisy’ variables (those not contributing well to DVMain) were dropped using a correlation threshold of 0.7 (Dormann et al., 2013) while the variables contributing meaningfully to adoption (DVMain) in each experiment were selected for further analysis. However, the data classes were still imbalanced. Resampling, synthetic data generation and class balancing were therefore done on the new sample dataset after data pre-processing (Kotsiantis et al., 2005). See chapters 6 And 7 above for details

8.2.1 Addressing Class Imbalance Using Synthetic Minority Over Sampling Technique (SMOTE) for ML application.

Before embarking on feature engineering, the distribution of the dependent variable was checked to ensure adequate representation of the classes. DVMain, the dependent variable, represents the level of adoption and has 5 classes, coded as follows (1-20)%: very low OSC adoption rate on projects discussed- coded as class 1, (21-40)%: low adoption rate and coded as class 2, (41-60)%: average adoption rate and coded as class 3, (61-80)%: high adoption rate and coded as class 4, (81-100)%: very high adoption rate and coded as class 5). However, an initial data processing (of the multi-class classification) showed that three of the classes of DVMain (Classes 1, 4 and 5) had low-frequency count and therefore reflected only one instance par class. Meanwhile, stratified sampling requires a minimum of two (2) instances par class to ensure each class is represented in both train and test splits (Kotsiantis, 2007; Kubat, 2017), thus requiring resampling.

To resample, over-sample, under-sampling and the synthetic minority over-sampling technique (SMOTE) were considered. Default Over-sampling involved synthesising more data for lower

classes to be at par with the class with the highest frequency. This implied that more synthetic data would be used for classes with less frequency. Default under-sampling implies a loss of original data as all data would be trimmed to the class with the lowest frequency. Neither is a good option for prediction in this case (Fernández, García, et al., 2018). This necessitates the need for an alternative class balancing that ensures adequate class representation. To this end, SMOTE was preferred.

SMOTE is an advanced statistical sampling technique that creates new artificial instances, employing the neighbourhood knowledge around a given minority class based on the K-Nearest Neighbour approach and interpolation (Chawla et al., 2002). Smote has been widely reported for its efficiency, simplicity in the design of its procedure, robustness and success when applied to different types of problems and domains, inspiration to surmount class imbalance issues and its significant contribution to new supervised learning paradigms including multi-label classification like this study (Chawla et al., 2002; Fernández, García, et al., 2018; Matharaarachchi et al., 2024). It has been described as the ‘de-facto’ standard framework for addressing imbalanced data (Matharaarachchi et al., 2024). It has over time developed variants like ExtSmote, ASmote, BGMM Smote among others (Fernández, García, et al., 2018; Hussein et al., 2019; Matharaarachchi et al., 2024). **Table 8.1** gives the class distribution of the training dataset before and after applying SMOTE resampling technique.

Table 8.1: DVMain Class distribution before and after resampling

S/No	DVMain Class distribution before resampling		DVMain Class distribution after resampling	
	Class	Count of Member	Class	Count of Member
1.	1	41	1	76
2.	2	76	2	76
3.	3	59	3	76
4.	4	35	4	76
5.	5	41	5	76

As a last layer class-balancing measure, this study used stratified K-fold validation, where $k=5$ to improve the robustness of the trained datasets. Precisely, stratified K-fold CV was used as against just K-fold CV because stratified K-fold ensures an even distribution throughout the classes. Only the training datasets in each experiment were subjected to stratified K-fold cross-validation (CV). *Refer to Figure 8.2* for CV details.

8.3 Machine Learning Approach

Machine Learning (ML) is a powerful tool that enables computers to learn from data and make intelligent decisions (Jordan & Mitchell, 2015). It can be supervised, unsupervised or reinforcement learning (LeCun et al., 2015). The supervised learning approach was adopted in this study because the models were developed by training them with a known data rather than allowing them to learn by themselves (Kotsiantis, 2007). ML has been found to have a wide range of applications across several industries and has transformed how problems are addressed and how decisions are taken (Bishop, 2006). ML is an evolving advancement in Artificial Intelligence (AI) and offers highly sophisticated, accurate, or near-accurate predictions (Domingos, 2012).

Machine Learning model development is an organised process of designing, training, evaluating and optimising algorithms to learn patterns from data and make informed predictions or decisions (Jordan & Mitchell, 2015; Kubat, 2017). It starts with defining the problem being addressed (in this case, OSC adoption), then pre-processing the data, feature selection and engineering, algorithm selection, training, (validation), testing and optimising performance (Kelleher et al., 2015). ML Model development usually aims to develop a model that generalises well on data initially unseen, thus, offering accurate and reliable predictions.

As a credence to the ML approach in identifying the most critical factors influencing the adoption of OSC in the UK, this study opted for developing a predictive model as one of the objectives of this study for its aim. The study carried out multiple experiments with different machine algorithms and selected the experiment with the highest possible measure for both accuracy and AUC. Accuracy and AUC are standard complimentary performance measures in classification tasks and are widely used to appraise model performance and generalisability. While accuracy measures the proportion of correct predictions, AUC-ROC accounts for class imbalances and provides insight into how well the model distinguishes between different classes and overall performance (Luo et al., 2019).

This study identified classification as the most appropriate modelling technique owing to the categorical nature of the target variable, DVMain (*See Section 8.2.1*) (Rashidi et al., 2023). Classification models have been adjudged very suitable for predicting discrete labels or classes, especially when the outcome variables are nominal or ordinal (Han et al., 2012b). Since the dependent variable (DVMain) falls into categorical classes, with an ordered category

representing adoption levels (Han et al., 2012b), classification models such as decision trees, support vector machines and some ensemble learners are appropriate for model development.

As no universally superior model fits all problems, the process of selecting an ML algorithm was cautiously implemented, in accordance with the ‘No Free Lunch (NFL) Theorem’ (Wolpert & Macready, 1997), which states no one algorithm performs best across all possible problems. As a result, ten (10) common classification algorithms that are considered suitable from the commonly reported classification algorithms that could address the specific data distribution, problem structure and domain context (Zhou et al., 2020) were carefully selected.

The model development relied on the generalisability and ease of interpretability of accuracy and AUC-ROC as the core evaluation metrics of the model development to aid understanding CI stakeholders who may lack the expertise to pilot complex AI models (Doshi-Velez & Kim, 2017). To aid explainability of results, the study adopted models that are easily interpretable for non-computing or non-AI experts, thus ensuring transparency while still mindful of good accuracy. Rudin, (2019) argues that using inherently interpretable models in high-stakes settings, where post-hoc explanation may be insufficient, ensures the model’s decision process can be easily traced and understood- a valuable trait in domains like construction management. (Yin et al., 2024). Therefore, ensuring interpretability was not only a technical goal of this development but also a strategic requirement to foster stakeholder trust and inspire confidence in the results presented.

The selection of ten (10) ML algorithms required some degree of trade-offs among the algorithms as this is a recommended practise in the field of AI/ML since no single ML algorithm outperforms another in all real-life applications (Wolpert, 1996). The diversity of

models supports uncovering more robust solutions and mitigates bias tied to specific algorithm assumptions (Nussberger et al., 2022). This strategy acknowledges the NFL theorem and supports the generalisation across various sub-patterns in the data. This is a necessary step when dealing with real-world heterogeneous data like that of construction project variables.

Thus, in developing a model fitting for predicting critical factors that influence OSC adoption, the experiment was performed with the significant features (factors) selected from a robust feature selection process from MCC and BC using both Mode and KNN imputation. The pre-processing steps ensured both good data quality and representation, setting a strong foundation for trustworthy model outputs. *Refer to figure 8.1.*

8.4 Machine Learning Model Development

The experiment used 10 FS algorithms that have been adjudged as being very applicable to categorical data by scholars in each case (*See section 7.2.1*). The four datasets from the FS exercise were used for model development. The four datasets were split into ratios 80:20 and 70:15:15. The splitting approach is discussed below.

8.4.1 Data Splitting

Data splitting is an ML model evaluation strategy employed in predicting how well the model performance is generalisable. It gives some assurance on the performance of the selected model(s) when applied in real life (Kelleher et al., 2015). The splitting process provides confidence on the selected models by mitigating overfitting risks and also provides insights into how the model might behave on new datasets (Bishop, 2006). The splitting process has several strategies. A simple and common approach is the training-test splits where data is

divided into training the model and evaluating its accuracy on unseen data. The ratios can be 80:20, 70:30, 60:40, and such likes (Joseph, 2022; Nguyen et al., 2021). To enhance the model's development process, some studies include a validation split as a second layer before testing, giving rise to the training, validation and testing splits (Kuhn & Johnson, 2013). Using a ratio approach to split datasets into training, validation and testing datasets for model development has been reported to be helpful in addressing challenges associated with model overfitting (Kuhn & Johnson, 2013). Adding the validation layer is necessary when hyperparameter tuning or multiple experiments are involved. Noting the challenge of model over-fitting associated with many reported articles on Machine Learning algorithms, creating a validation dataset in the split became necessary to ensure models do not give false accuracy resulting from already known data (Han et al., 2011). The validation splits can be 80:10:10, 70:20:10, 70:15:15, 60:20:20 (Joseph, 2022; Q. H. Nguyen et al., 2021). This splitting approach ensures that there is data to validate the training results before testing, thus eliminating potential model overfitting that could arise from using already identified data when such data is used for testing. Having experimented with 80:20 and 70:15:15 splitting ratios in a multi-class classification, the test accuracy results were unimpressive, with best test accuracy performance barely above 50%. More steps, like using cross validation and recalibrating the dependent variable into binary class were taken to improve the models' accuracies.

To further reduce variability in model development and provide more accurate estimate of the model on unseen dataset, researchers sometimes employ cross-validation, which splits the training dataset into subsets, performing training on other subsets while validating on the held-out one. For example, in a 5-fold cross validation, training is conducted on four folds while

testing is performed on a fold. This process is iterated until all the five folds have been used to test. The average of the five cycles of cross-validation results is the estimated test accuracy.

In experiments where class imbalance is a challenge, Stratified K-Fold Cross Validation is usually recommended. This addresses uneven class distribution limitations and to ensure a balanced and even class distribution across all folds, (Pedregosa et al., 2011). The stratified K-fold ensures the five classes of the dependent variable (in MCC approach) were preserved in every fold and that each fold represents the same distribution of target classes as the entire dataset (Fernández, García, et al., 2018). It also ensures that minority classes are always present in each fold, thus improving the reliability of metrics like precision, recall, F1 Score and, consequently, the model accuracy (Buda et al., 2018). Additionally, stratified K-fold prevents data leakage and ensures no fold misses important class information during hyperparameter tuning (Varma & Simon, 2006). In this study, the number of folds, $k = 5$. *See figure 8.2.*

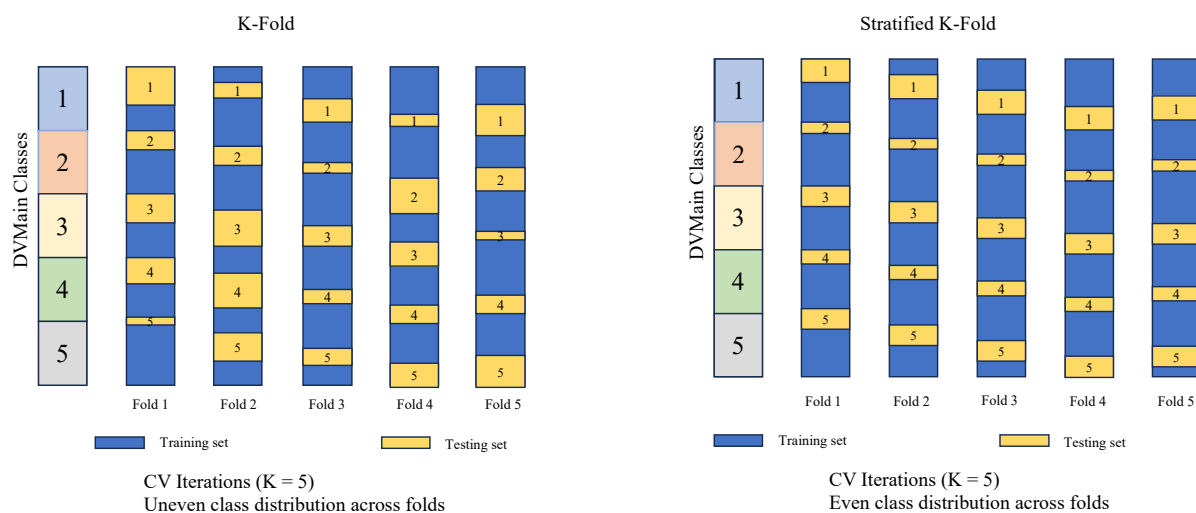


Figure 8.2 (a & b): Stratified Cross-Validation and Cross-Validation description

Adapted from Mahesh Huddar, (2022)

The use of cross-validation ensures a robust dataset in the model development, accounting for improved variability across folds, fairness-(ensuring that the selection and evaluation of features is not biased) and reproducibility (ensuring results can be reproduced by setting a random seed) (Kohavi & John, 1997). The adoption of Stratified K-Fold also ensures that the multi-class nature of the dependent variable (DVM_{ain}) is taken into consideration, unlike the basic K-fold cross-validation approach that is more applicable to binary classifications (Bengio & Grandvalet, 2004; Kotsiantis, 2007).

Stratified K-fold cross-validation was applied to only the training splits of the datasets for the selected variables from FS. Each splitting (i.e., 80:20 and 70:15:15) in multi-classification was re-run with hyperparameter tuning. Hyperparameter tuning was conducted on the models to achieve better results for the models through grid search (an optimisation algorithm). Though the training model parameters were not saved in pickle files, the codes were written to have the parameters saved into in-memory and repeat the exact model weights for validation and test datasets. Results from the experiments were tabulated out and the best models for each experiment were noted. It was observed that the multi-class classification test accuracy results rose to from below **50%** to **58.3%** as best accuracy. With the performance not impressive enough still, the study opted for binary classification (BC) experimentations (Jerez et al., 2010). The results for BC showed significant improvement for accuracy. Also, the AUCs of both MCC and BC showed reliably improved values. The best performing model (void of overfitting likelihood) was noted for ultimately developing the adoption predictive model for identifying the key influencing factors of OSC adoption in the UK construction industry whether using a multi-class or binary classification method. See *Figure 8.1* for the architecture of the ML development.

8.4.2 List of Algorithms used for Model Development

The study selected ten (10) Machine Learning classification models to evaluate the critical OSC influencing factors identified through feature selection using the significant features' datasets. The preferred models among the commonly reported classification models are Random Forest (RF), Support Vector Classifier (SVC), Logistics Regression (LR), Decision Tree (DT), KNeighbours (KN), GradientBoosting (GB), ExtraTrees (ET), Multi-Layer Perceptron (MLP), Forward Feed Neural Network (FFNN) and Backward Feed Neural Network (BFNN). These models are widely used in practise for classification tasks and provide a robust basis for evaluating performance across various metrics and data complexities (Fernandez-Delgado et al., 2014). These models are briefly discussed below:

Random Forest (RF): RF is a tree-based ensemble learning algorithm that combines multiple decision trees on various data sub-samples to enhance accuracy and reduce overfitting (Breiman, 2001). It handles both numerical and categorical data effectively, making it highly suitable for diverse feature sets and allows for feature importance analysis (Biau & Scornet, 2015). It handles multicollinearity effectively and reduces the influence of highly correlated variables (Strobl et al., 2007). Its bootstrapping and random feature selection contribute to good interpretability, high generalisation capability and less prone to overfitting (Cutler et al., 2007; Genuer et al., 2010).

Support Vector Classifier (SVC): It is a powerful and effective classification model suited for small to medium size datasets with high-dimensional features. Its use of kernels tricks allow for non-linear classification modelling effectively, and it is robust to overfitting in high-

dimensional spaces and it is effective in distinguishing classes with complex boundaries (Cortes & Vapnik, 1995).

Logistics Regression (LR): LR is a simple and interpretable linear model ideal for binary and multiclass classification problems. It assumes a logit-linear relationship between independent variables and the outcome and performs well when features are independent and linearly separable. Its low computational cost and clear coefficients make it suitable for feature interpretability in applied domains (Hosmer et al., 2013)

Decision Tree (DT): Decision Trees are non-parametric models that learn simple decision rules inferred from data features. They are highly interpretable, can handle both numerical and categorical variables (James et al., 2013). Though prone to overfitting, this can be mitigated by pruning (i.e., removing the parts of the trees that do not provide significant power in predicting target variable, especially causing noise within the training data) or the use of ensemble methods (Quinlan, 1986).

KNeighbours (KN): it is a simple, non-parametric, instance-based, classification ML algorithm effective for small datasets. It classifies a sample based on the majority label of its nearest neighbours in the feature space. It captures local patterns and non-linear boundaries well. KN is a simple and interpretable choice for small, cleaned dataset without assuming an underlying distribution (Cover & Hart, 1967).

GradientBoosting (GB): It is an ML algorithm that efficiently handles imbalanced datasets, missing values and categorical variables (Chen & Guestrin, 2016). It is a powerful ensemble technique that builds sequential weak learners (often, decision trees), optimising errors of

previous models. It adds depth to the model comparison, especially for non-linear relationships (Friedman, 2001). It handles complex feature interactions well for features that may not be well-explored by tree-based models and performs highly with minimal feature engineering (Natekin & Knoll, 2013). It exhibits high performance in competitions and real-world applications and often achieves state-of-the-art results on tabular data (Prokhorenkova et al., 2019).

ExtraTrees (ET): It is an ensemble method similar to RF, but with higher randomness in splitting criteria. Extra Trees is also known as Extremely Randomised Trees. It has a randomised splits ability, which can further reduce variance, and it is computationally faster than RF. It is efficient for feature importance analysis, high-dimensional or noisy datasets and works well with correlated values (Geurts et al., 2006).

Multi-Layer Perceptron (MLP): MLP is a type of feedforward neural network that includes one or more hidden layers and uses non-linear activation functions. It is effective for capturing complex, non-linear patterns in data and can handle interactions among features better than other simpler models like... It works well when combined with feature engineering (LeCun et al., 2015). It employs the power of neural networks for non-linear relationships, making it a modern arsenal for ML tasks.

Forward Feed Neural Network (FFNN): It is the simplest form of the neural networks, where information flows only in one direction (input to output without cycles). It is effective for tabular data with no temporal or sequential relationships and acts as a solid baseline for neural network models. Its simplicity makes them suitable for structured data modelling (Werbos, 1990).

Backward Feed Neural Network (BFNN): Commonly paired with FFNN, it uses backpropagation for optimising FFNNs' weight by using gradient descent based on the error minimisation strategy thus improving learning efficiency. It enhances learning with sequential dependencies. This model is foundational to modern deep learning architectures (Rumelhart et al., 1986).

8.4.3 Model Evaluation Measures

Upon resampling the data, the performance of selected trained models was evaluated using appropriate and standard classification measures such as Precision, Recall, F1 score, Support, Accuracy and Area Under the Curve (AUC). These measures are vital in determining the effectiveness and generalisability of models (Sokolova & Lapalme, 2009). The AUC-ROC score summarises this curve into a single value between 0 and 1, where values closer to 1 indicate better classification performance. While accuracy alone may be misleading in imbalanced datasets, AUC provides a robust measure that considers all threshold levels, and it is threshold-independent, making it particularly useful in classification circumstances (Bradley, 1997). These evaluation metrics are elaborated upon below.

Confusion Matrix: A confusion matrix is a performance measurement tool used to evaluate a classification model's accuracy. It is a fundamental tool in classification problems and provides detailed insight into the performance of a model by detailing the counts of correct and incorrect predictions. The confusion matrix is known to clarify the errors a model is making during evaluation. While it is a bit straight forward in a binary classification, it quite complex in a multi-class classification where the values are computed per class and then average using macro, micro or weighted strategies depending on the level of the dataset imbalance classes

(Sokolova & Lapalme, 2009). Given that the study's dependent variable has five ordinal classes, the confusion matrix provides clarity on how well the models classify each adoption level-ensuring that no single class dominates accuracy interpretation and that no minority classes are ignored. For instance, where a class (e.g. Class 4, 61-80%, with 35 frequencies) has few instances, the confusion matrix will reveal if the model consistently misclassifies it, despite high overall accuracy. The insight is vital for fair model evaluation in real-world adoption scenarios.

The key elements in a Confusion matrix table are:

True Positive (TP): *an indication of the number of instances correctly predicted as positive,*

True Negative (TN): *an indication of the number of instances correctly predicted as negative,*

False Positive (FP): *an indication of the number of instances incorrectly predicted as positive, also known as Type 1 error*

False Negative (FN): *an indication of the number of instances incorrectly predicted as negative, also known as Type 2 error.*

From the Confusion Matrix, accuracy, precision, recall (sensitivity or true positive rate) and specificity (True Negative Rate) are calculated to evaluate a model.

Accuracy: The ratio of correctly predicted instance to the total available instance, given by the equation:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

Precision: This is the ratio of true positives to the total actual predicted positives. The higher precision means fewer false positives. It is a reflection of how ‘precise’ the model is in in classifying a class. Precision equation is given by,

$$Precision = \frac{TP}{TP + FP}$$

Recall (Sensitivity or True Positive Rate): It is the ratio of true positives to the total actual positives as given dataset. It indicates how well the model can identify all relevant instances in a class. The equation for precision is given below:

$$Accuracy = \frac{TP}{TP + FN}$$

F1-Score (True Negative Rate): This is the ratio of true negatives to the total actual negatives in a given dataset. It combines precision and recall into a single metric and provides a balance between them.

$$F1 = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

Specificity (True Negative Rate): The ratio of true negatives to the actual negatives

$$Specificity = \frac{TN}{TN + FP}$$

False Positive Rate: The ratio of false positives to the actual negatives.

$$False\ Positive\ Rate = \frac{FP}{TN + FP}$$

Support: This provides an understanding of the distribution of actual instances across different classes. It is the number of instances in each class.

Random State: It is an ML/data analytics parameter that controls the randomness in various processes like data splitting, feature selection, resampling and model development, ensuring the reproducibility of results and the reliability of experiments (Géron, 2019). It is a seed value for a random number generator. In feature engineering, (for example, in data normalisation and standardisation, missing data imputation using KNN, or resampling and synthetic data generation), random state affects the feature engineering techniques. Though, some methods like MinMax Scalar, Standard Scalar and Robust Scalar do not require a random state while others like Power Transformer and Quantile Transformers, which use sampling, can be impacted by random state (Pedregosa et al., 2011). In feature selection, it ensures the same shuffling is applied across runs, leading to consistent feature ranking, guaranteeing the selected most important features remain consistent. Though not all methods involve randomness, when a random state is not set for an iteration that involves a stochastic model (e.g., Random Forest), the samples generated at every run differ and can lead to non-reproducible results (Raschka & Mirjalili, 2019). In model development, RS ensures consistent splits across runs by assigning the same data points to train and test sets each time or ensures each fold contains the same data points in every run. The application of RS prevents fluctuations in results and ensures model accuracy and AUC-ROC accuracy remains consistent across iterations.

ROC (Receiver's Operating Characteristics) Curve: This is a graphical plot or representation used to evaluate and illustrate the performance of a classification model at various thresholds. It displays the sensitivity (TPR) on the y-axis against the Specificity (FPR)

on the x-axis across all possible threshold values. The ROC curve is indicative of the trade-offs between sensitivity and specificity, and it provides insights into the models' ability to differentiate between classes.

Area Under the Curve of Receiver's Operating Characteristics (AUC-ROC): The AUC-ROC, often called 'AUC' is the area under the ROC curve. It quantifies the overall ability of the model to distinguish between the positive and negative classes, with a single scalar value ranging from 0 to 1. AUC-ROC is insensitive to class imbalance because it comprehensively evaluates model performance across different threshold levels, thus providing a fair assessment regardless of class distribution.

The most relevant measures in the model development for this study are Accuracy and AUC performance. While accuracy is simple and intuitive (Delovski, 2023), and also a build up from some of the measures highlighted above like TP, TN, FP and FN, it is not as entirely reliable as AUC (Movahedi et al., 2023). It fluctuates with unseen data (Thölke et al., 2023), fails with imbalanced classes (Richardson et al., 2024) and does not distinguish between types of errors (Delovski, 2023). Conversely, AUC summarises the ROC curve into a single metric (Richardson et al., 2024), maximising trade-off between sensitivity (recall) and specificity and this is great for model's discriminative ability, i.e., threshold-independent (how well the model ranks positive instances higher than negatives (Richardson et al., 2023). It is robust for imbalance dataset (Richardson et al., 2023) and remains relatively stable with unseen datasets (McDermott et al., 2024).

8.4.4 Developing the Models.

The sub-sections above highlighted the model development preparation steps taken while this sub-section addresses the evaluation of model results. First, the models were evaluated using the highlighted algorithms and measures. The model performances were then compared before selecting the bests in each experiment, and finally, the best performing model. The scope of this research does not include deployment and maintenance due to time constraint, but publications are underway to address deployment and real-world application possibilities.

Training ML models involves using training data to learn patterns and relationship within the input features (independent features) and the output labels (dependent feature (DVMain)). This quality of this training process depends on influences such as data-preprocessing, algorithm choice and hyperparameter configuration (all of which have been captured above). A well-trained model minimises the training errors while preserving the generalisability, i.e., the ability of the model to perform well on unseen data (Hastie et al., 2009). During model evaluation, a part of the dataset was held out for validation and/or testing to appraise the model's performance on unseen data. This is necessary as relying on test dataset accuracy alone may be misleading, or it may ignore minority class performance (Saito & Rehmsmeier, 2015). Hence, a multi-metric evaluation process was necessary for the holistic view of the models' performance.

The results of the different models are compared using performance metrics and visual tools (e.g., ROC curves or precision-recall plots). For instance, deep learning models yields higher accuracy (Egwim et al., 2021), but simpler models offer greater interpretability desirable in a public sector application like healthcare, construction, to mention but a few. Also, no single

algorithm performs best across all problem domains therefore, necessitating an empirical comparison. Multi-metric evaluation is thus crucial for assessing the trade-offs between interpretability and performance, as this research involves addressing industry realities with stakeholders and policy makers regulating the industry.

Furthermore, the models were tuned with hyperparameter methods like grid search to enhance performance. Additionally, cross-validation, specifically, stratified K-Fold was adopted during the training to prevent overfitting while ensuring the model learns general patterns. To achieve a rigorous evaluation in selecting the best predictive model, the approach used four (4) data sets, ten (10) selected algorithms and nine (9) random states to evaluate. A report of the training, validation and test results are presented in *Chapter 9*, including test and AUC-ROC accuracies for all the multi-metric experiments conducted.

This chapter partly fulfils objective 5 by developing predictive models. The next chapter evaluates the model results and identifies the best predictive one, thus satisfying objective 5 and the research overall aim. It also compares finding from other aspects of the research like the SLR, interviews and hypothesis.

CHAPTER 9

9.0 RESEARCH FINDINGS AND DISCUSSION

Chapter Overview

This chapter highlights the research findings derived from the of the various steps taken in the preceding chapters, culminating in a comprehensive discussion of the results. It details the findings from the research objectives and discusses their implications for practise, policy and academia.

9.1 RESEARCH FINDINGS

9.1.1 *Systematic Literature Review (SLR) Outcomes*

The study conducted three SLRs to unravel the various issues bordering around OSC adoption. The outcome of the SLRs in relation to research Objective 1 are highlighted below.

***Objective 1:** To conduct systematic literature review (SLR) in identifying and synthesising commonly reported OSC adoption influencing factors across international contexts, including granular (un)popular ones.*

Following the aim of the study and the philosophical stance employed in addressing the aim, the study towed the route of exploratory research, thereby not conditioned to adopting any particular framework. This enabled the study to explore deep into OSC influencing factors.

SLR 1 content analysis findings (*Refer to Sections 2.3.3 and 2.3.4*) identified two hundred and eighty-nine (289) OSC adoption driving issues which were categorised into forty-two (42) factors, streamlined into ten (10) sub-themes and finally into five (5) themes (*namely improved productivity, improved environment and safety, construction business and cost management,*

government intervention and supply chain and site management). Similarly, three hundred and thirty-nine (339) inhibiting issues, categorised into eighty (80) factors, streamlined into fifteen (15) sub-themes and eight (8) broad themes (*namely supply chain management, design and construction technology, construction industry management, OSC knowledge, communications and data management, attitude, funding, policies and interventions and environmental sustainability*) were identified.

SLR 1 findings highlighted that attempting to use broad or well-known themes to address factors influencing OSC adoption results in overlaps and lopsided understanding of which factors truly influence OSC adoption. The review therefore recommends that to understand the factors influencing OSC adoption and their criticality, the themes should be broken down into their constituent elements and then measure the impact of such elements on adoption.

SLR 2 (*Refer to Section 2.3.2*) noted that the fragmented and diverse nature of the construction industry largely impacts OSC adoption level. Hence, a narrow research approach, which fails to drill deeper into probable causal issues, may not be sufficient to address the low OSC adoption state and cannot determine the very critical factor responsible for the low adoption. The review thus presented the need for a more holistic approach to viewing, appraising and evaluating OSC adoption beyond a ‘face’ value approach. The review identified lack of documented OSC project as a probable challenge to rigorous and detailed research on OSC. Hence this study attempted gathering OSC project information in analysing the critical adoption influencing factor.

The review equally spotted lack of theoretical underpinning on OSC adoption studies and lack of adoption framework developments- a pattern that is prominent in most CEM studies. The

review thus encourages further studies to employ an encompassing theoretical guide(s) that caters for construction stakeholders (professionals and non-professionals, adopter, potential adopters and non-adopters) to better understand the adoption challenges and ways to surmount them.

SLR 3 (*See Section 2.4.5*) employed the RIBA-PoW in exploring the state of OSC adoption in the UK. It found the most researched OSC adoption phase is RIBA-PoW Stage 5 (Manufacturing and Construction) while the under researched phases are the design phase, encompassing stages 2, 3, and 4 of RIBA-PoW. The review unearths two streams in the adoption pursuit- the industry professionals, allied partners and workers; and other non-professional stakeholders (mostly end-users). While the first stream possesses some form of knowledge and awareness on OSC, the second have little or no knowledge about OSC.

This review thus recommends that for wider OSC adoption to be in the UK, both streams have to be considered, particularly the end-users who are the final ‘consumer’ and who also possess the numbers.

9.1.2 Qualitative approach Outcomes

***Objective 2:** To evaluate and establish, from the globally identified OSC adoption influencing factors, the relevant and applicable ones to the UK context through qualitative interviews with UKCI professionals.*

The interview content analysis findings highlighted more specific factors influencing OSC adoption in the UK than the SLR 1. The interview noted fourteen (14) OSC adoption influencing factors by weight (i.e., frequency of mention from transcript analysis). Supply chain management emerged as the most influencing factor by weight, followed by timesaving

and then productivity; with the three amassing over 45% of the total weight. Stakeholders' influence, improved health and safety and education and training are the identified three least influencing factors, aggregating less 15% of the total weight (*See Table 5.3*). The findings from the content analyses informed the hypothesis developed

Objective 3: *To triangulate findings from the interview analysis with a UK-focused SLR in designing a UK context-specific survey instrument for quantitative data collection.*

The interview analysis also had thematic analysis which looked beyond the frequency of mention by paying attention to the latent meaning in the interview discussions by textually examining the fourteen themes influencing OSC adoption in the UK (*See Section 5.5.3*). Each theme is observed to have constituent elements (sub-themes). A total of seventy-four (74) underlying issues were identified. These issues were operationalised into survey questionnaire and refined to make the questionnaire concise as much as possible (*See Appendix 9*). The questionnaire development is also guided by findings from SLR 3- a UK-focused review on the state of OSC adoption in the UK.

All the findings highlighted above have been discussed in the respective chapters but summarised here for the purpose of triangulating the results with the quantitative findings. The quantitative findings are therefore presented below and discussed.

9.1.3 Quantitative approach Outcomes

Objective 4: *To identify and establish the most critical factors influencing OSC adoption in the UK through quantitative analysis and feature selection (FS) techniques using ten (10) commonly identified FS algorithms/models.*

Hypothesis findings, using Chi-Square, identified twenty-four (24) variables (*Refer to section 6.3.3*) from eight (8) constructs (Perception, Design and Construction Factors, Awareness, Supply Chain and Logistics, Construction Management and Cost, Project Knowledge and Data, General Information and Project Details) as having a significant relationship with the dependent variable, DVMain.

Feature Selection Results

Two streams were adopted in analysing the most critical factors influencing the adoption of OSC in the UK. First was multi-class classification (MCC) and then Binary classification (BC). Prior to feature selection, the data was wrangled and engineered for features (variables) that contribute significantly to OSC adoption. Feature engineering strategies employed included replacing missing data with **mode** and **KNN** imputations. Spearman correlation was used to address multi-collinearity and thus high dimensionality. The significant features (factors) from the streams of feature selection were used to establish the critical OSC influencing factors in both multi-class and binary classification, and then the most critical OSC adoption influencing factors in the UK. The critical factors from MCC and BC were compared with the findings from SLR, qualitative analysis and hypothesis result. It emerged that 87.5% (14 of 16) of factors from MCC and 80% (8 of 10) from BC agreed with the significant features from hypothesis testing, SLR and qualitative analysis as being critical to OSC adoption in the UK. (*See 9.1 and 9.2*).

Multi-classification Output: Irrespective of the missing data imputation method adopted (KNN or Mode), AW4, CMC6, CMC9, CMC15, DCF1, DCF10, PD3, PD8, PD9, PD11, PKD2, PP5, PRS8, SCL7, SCL8, SCL11, (in no particular order) emerged in all feature

selection experimentation carried out with MCC and are adjudged the variables with a **high critical** influence on OSC adoption in the UK using MCC.

Table 9.1: Comparison of Factors with very high likelihood OSC adoption influence in the UK according to Multi-Class Classification with SLR and Qualitative Analysis

S/No	Critical OSC Influencing Factors from MCC	Construct	Variable Tag	Present in SLR	Present in Qual Analysis	P-Value
1.	Awareness of planning authorities: To what extent was the knowledge level of planning authorities concerning Offsite Construction (OSC) construction methodologies influence their decision to appro...	Awareness Factor	AW4	Yes	Yes/ Medium	0.001595
2.	Availability of construction industry SMEs' support for the OSC project	Construction Market and Cost	CMC6	Yes	Yes/ Medium	0.002705
3.	Initial setting up cost (1st instalment paid to kick start the project)	Construction Market and Cost	CMC9			0.008616
4.	Mortgage Accessibility (with respect to adopting OSC on the project)	Construction Market and Cost	CMC15			0.00108
5.	Design lead time (Is the amount of time required before freezing OSC design quicker or slower)	Construction Market and Cost	DCF1			0.004284
6.	Scalability (Repeatability of design and project modules)		DCF10			0.000253
7.	What class of building/infrastructure was developed for the project?	Project Details	PD3			0.00079
8.	What client type owned the OSC project?		PD8			0.000217
9.	What was/is the OSC project duration?		PD9	Yes	Yes/ Medium	1.31E-05
10.	How long would it have taken the project if OSC was not considered or used?		PD11	Yes	Yes/ Medium	0.000228
11.	How much consideration was given to availability of past	Project Details	PKD2	Yes	Yes/ Medium	0.000853

	OSC Project Data to support adopting OSC for the project?	Project Knowledge and Data				
12.	Monotonous perception (A common misconception that OSC is limited to box-like designs and unsuitable for creative or flexible architectural solutions).	OSC Perception Issues	PP5	Yes	Yes/ Medium	***
13.	OSC Building whole life cycle (Overall OSC building performance during building lifetime when compared with traditional construction)	Policy, Regulation and Sustainability (12 Items)	PRS8			***
14.	Road width that fits truck size	Supply Chain and Logistics	SCL7	Yes	Yes/ Medium	2.17E-06
15.	Access Road to the site that fits truck size		SCL8	Yes	Yes/ Low	0.001062
16.	Site Hedging (Availability of site storage area for components and modules)		SCL11			0.003539

*** Variables (Factors) did not exhibit significance during hypothesis ($p\text{-value} > 0.01$)

Binary Classification Output: In a similar vein, using BC, AW4, DCF1, DCF4, DCF10, PKD2, PP5, SCL7, SCL8, SCL10, SCL11 emerged in all feature selection experimentation carried out and are adjudged the variables with a high critical influence on adoption of OSC in the UK.

Table 9.2: Comparison of Factors with high criticality OSC adoption influence in the UK according to Binary Classification with SLR and Qualitative Analysis

S/No	Survey Question (Variable Name)	Construct	Variable Tag	From SLR	From Qual Analysis	P-Value
1.	Awareness of planning authorities: To what extent was the knowledge level of planning authorities concerning Offsite	Awareness Factor	AW4	Yes	Yes	0.001595

	Construction (OSC) construction methodologies influence their decision.					
2.	Design lead time (Is the amount of time required before freezing OSC design quicker or slower)	Design and Construction Factors	DCF1	Yes	Yes	0.004284
3.	OSC Building (Construction) material quality (a belief that OSC construction material is not of quality as traditional construction material)		DCF4	Yes	Yes	0.002473
4.	Scalability (Repeatability of design and project modules)		DCF10	Yes	Yes	0.000253
5.	How much consideration was given to availability of past OSC Project Data to support adopting OSC for the project?	Project Details Project Knowledge and Data	PKD2	Yes	Yes	0.000853
6.	Monotonous perception (A common misconception that OSC is limited to box-like designs and unsuitable for creative or flexible architectural solutions).	OSC Perception Issues	PP5			***
7.	Road width that fits truck size	Supply Chain and Logistics	SCL7	Yes	Yes	2.17E-06
8.	Access Road to the site that fits truck size		SCL8	Yes	Yes/ Low	0.001062
9.	Ratio of site size to buildable area		SCL10			***
10.	Site Hedging (Availability of site storage area for components and modules)		SCL11			0.003539

*** Variables (Factors) did not exhibit significance during hypothesis ($p\text{-value} > 0.01$)

The factors common to both approaches are **AW4, DCF1, DCF10, PKD2, PP5, SCL7, SCL8** and **SCL11** and the constructs common to both are **Awareness, Design and Construction Factors, Project knowledge and Data, Perception, Supply Chain and Logistics (5 constructs)**

Majority (87.5%, 14 of 16) of the critical OSC influencing factors identified in multi-class and (80%, 8 of 10) binary classification approaches exhibited good degree of importance when

tested hypothetically; except PP5 and PRS8 for MC and PP5 and SCL10 for BC. Overall, seven factors exhibited criticality across multi-class and binary classifications except **PP5** and are reported to be the **most critical factors** influencing on OSC adoption in the UK within the confines of this research and the data used. These factors are expounded upon under ***Section 9.2.1.***

***Objective 5:** To develop a ML predictive model with the identified critical factors using ten (10) commonly identified ML algorithms and determine the best-performing predictive model for OSC adoption in the UK.*

Four new sample datasets were generated from the feature selection exercise (***See list of datasets at the bottom of Section 7.2.2.***). The result of the scrutiny of the new sample datasets (as displayed in ***Tables 7.5 and 7.6***) from the feature selection leading to model development is presented below.

9.1.4 Machine Learning Model Results

The machine learning approach employed ten algorithms in developing model(s) suitable for predicting OSC adoption using the four different datasets from feature engineering (***See Section 7.2.2***) in an 80:20 and 70:15:15 splitting ratio. The experiments were performed for both MCC and BC, iterated through nine random states (RS) in each case. ***See Table 9.3(a-j)*** for detailed ML results. The model development results for both streams are presented by Random States.

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
42	Random Forest	0.4762	0.7759	0.4583	0.7417	0.3651	0.7009	0.3750	0.6935	0.7778	0.8385	0.7083	0.7778
42	SVC	0.3651	0.7343	0.4375	0.7209	0.3651	0.7423	0.3750	0.7358	0.7937	0.8469	0.7292	0.8469
42	Logistic Regression	0.3175	0.7245	0.2500	0.6875	0.3810	0.7035	0.3333	0.6781	0.8571	0.8469	0.7292	0.8469
42	Decision Tree	0.3651	0.6009	0.3542	0.5816	0.2698	0.5539	0.2500	0.5175	0.7460	0.6836	0.7917	0.7460
42	K Neighbors	0.4286	0.6997	0.4167	0.7008	0.3651	0.6679	0.2708	0.6824	0.7778	0.8032	0.7500	0.8032
42	Gradient Boosting	0.3968	0.7037	0.4375	0.6853	0.3968	0.6837	0.3125	0.6486	0.7778	0.8110	0.7292	0.7778
42	Extra Trees	0.4286	0.7565	0.4375	0.7547	0.3810	0.6915	0.4167	0.6886	0.8254	0.8283	0.7292	0.7292
42	MLP	0.2698	0.6847	0.3125	0.6356	0.4603	0.7128	0.3750	0.6667	0.7302	0.8074	0.6875	0.7302
42	Forward Feed NN	0.2698	0.6847	0.3125	0.6356	0.4603	0.7128	0.3750	0.6667	0.7302	0.8074	0.6875	0.7302
42	Backward Feed NN	0.3333	0.6953	0.3333	0.7163	0.4286	0.7392	0.3333	0.7157	0.8413	0.8971	0.7500	0.8971

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
45	Random Forest	0.3810	0.6740	0.2083	0.6316	0.3810	0.6997	0.2083	0.5966	0.7460	0.7512	0.7083	0.74
45	SVC	0.3333	0.7099	0.2917	0.6507	0.4603	0.7497	0.3125	0.6598	0.7460	0.7691	0.7292	0.74
45	Logistic Regression	0.3492	0.6568	0.2083	0.6084	0.4286	0.7026	0.2292	0.6233	0.7619	0.7847	0.6667	0.68
45	Decision Tree	0.2381	0.5222	0.1667	0.4665	0.2698	0.5339	0.1667	0.4768	0.6190	0.6226	0.6250	0.61
45	K Neighbors	0.3651	0.6591	0.2917	0.6605	0.4444	0.6575	0.3333	0.6076	0.6667	0.6806	0.6875	0.69
45	Gradient Boosting	0.3175	0.6267	0.2500	0.5842	0.3810	0.6807	0.2500	0.5935	0.6984	0.6579	0.6667	0.74
45	Extra Trees	0.3651	0.6801	0.2083	0.5906	0.3175	0.6865	0.2708	0.6241	0.7778	0.7392	0.7500	0.73
45	MLP	0.3016	0.6355	0.3125	0.6135	0.3810	0.6910	0.2917	0.6427	0.7302	0.7261	0.6458	0.73
45	Forward Feed NN	0.3016	0.6355	0.3125	0.6135	0.3810	0.6910	0.2917	0.6427	0.7302	0.7261	0.6458	0.73
45	Backward Feed NN	0.2540	0.6439	0.2917	0.5847	0.4444	0.7036	0.3542	0.6162	0.7460	0.7189	0.7292	0.74

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
50	Random Forest	0.4762	0.7285	0.3125	0.7334	0.3333	0.6547	0.2708	0.6570	0.7937	0.8457	0.8750	0.88
50	SVC	0.4127	0.7585	0.3750	0.7401	0.3492	0.7013	0.3542	0.7079	0.7302	0.8696	0.8333	0.89
50	Logistic Regression	0.3016	0.7190	0.3333	0.6723	0.3810	0.6893	0.2708	0.6286	0.7619	0.7584	0.8542	0.89
50	Decision Tree	0.3810	0.6093	0.3125	0.5917	0.3016	0.5518	0.2917	0.5599	0.6349	0.5891	0.7292	0.73
50	K Neighbors	0.3810	0.6954	0.3750	0.6949	0.3175	0.6397	0.3125	0.6730	0.7937	0.8343	0.7500	0.83
50	Gradient Boosting	0.3968	0.6854	0.3542	0.7019	0.3333	0.6688	0.3333	0.6025	0.7937	0.8433	0.8542	0.89
50	Extra Trees	0.3968	0.7039	0.2917	0.7042	0.3333	0.6689	0.3333	0.6537	0.7619	0.8523	0.8542	0.86
50	MLP	0.4127	0.6793	0.3542	0.6064	0.3175	0.6513	0.2292	0.5963	0.7460	0.7859	0.8333	0.86
50	Forward Feed NN	0.4127	0.6793	0.3542	0.6064	0.3175	0.6513	0.2292	0.5963	0.7460	0.7859	0.8333	0.86
50	Backward Feed NN	0.4444	0.7028	0.3125	0.6673	0.3175	0.6687	0.2500	0.6352	0.7937	0.8349	0.8333	0.90

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
55	Random Forest	0.3651	0.6773	0.2917	0.6568	0.4127	0.7147	0.2917	0.6804	0.7778	0.8278	0.7500	0.7500
55	SVC	0.3333	0.7295	0.3958	0.6541	0.3810	0.7477	0.4583	0.6785	0.8095	0.8517	0.7708	0.8333
55	Logistic Regression	0.3651	0.7264	0.3750	0.6171	0.4603	0.7297	0.4375	0.6519	0.7778	0.7727	0.7708	0.8409
55	Decision Tree	0.2540	0.5343	0.1875	0.4870	0.3492	0.5896	0.2292	0.5006	0.6667	0.6118	0.7083	0.6667
55	K Neighbors	0.3016	0.6342	0.3958	0.5804	0.3333	0.6648	0.3542	0.6293	0.7302	0.7123	0.6667	0.7407
55	Gradient Boosting	0.3492	0.6913	0.3750	0.6299	0.4286	0.7254	0.4583	0.6706	0.7143	0.7404	0.7083	0.7302
55	Extra Trees	0.3333	0.6665	0.3542	0.6637	0.3968	0.7186	0.3750	0.6532	0.7619	0.8068	0.7500	0.7708
55	MLP	0.2381	0.6298	0.2500	0.5471	0.3333	0.6747	0.3125	0.5898	0.7460	0.7859	0.7500	0.8000
55	Forward Feed NN	0.2381	0.6298	0.2500	0.5471	0.3333	0.6747	0.3125	0.5898	0.7460	0.7859	0.7500	0.8000
55	Backward Feed NN	0.3968	0.7077	0.3125	0.6084	0.3333	0.6793	0.3542	0.6171	0.7778	0.8385	0.7500	0.8409

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
60	Random Forest	0.4286	0.7013	0.3750	0.6936	0.4921	0.7698	0.3958	0.7135	0.6984	0.7721	0.6875	0.6875
60	SVC	0.4286	0.7153	0.4167	0.6760	0.4127	0.7571	0.4167	0.7104	0.7937	0.8098	0.6667	0.6667
60	Logistic Regression	0.3016	0.6769	0.2708	0.6561	0.3651	0.7042	0.3750	0.6707	0.7302	0.6902	0.6458	0.5833
60	Decision Tree	0.2698	0.5333	0.3333	0.5730	0.3333	0.5806	0.1875	0.4817	0.6349	0.5891	0.6250	0.5833
60	K Neighbors	0.3810	0.7025	0.4167	0.6731	0.4444	0.7742	0.4583	0.7212	0.7778	0.7584	0.6667	0.6667
60	Gradient Boosting	0.3175	0.6530	0.3125	0.6435	0.4444	0.7416	0.2708	0.6654	0.7143	0.7392	0.6875	0.6667
60	Extra Trees	0.3968	0.6894	0.2708	0.6701	0.3968	0.7538	0.3542	0.6844	0.7460	0.7494	0.6875	0.6667
60	MLP	0.3333	0.6591	0.3333	0.6233	0.3968	0.6990	0.3125	0.6217	0.6667	0.6998	0.5625	0.5833
60	Forward Feed NN	0.3333	0.6591	0.3333	0.6233	0.3968	0.6990	0.3125	0.6217	0.6667	0.6998	0.5625	0.5833
60	Backward Feed NN	0.3810	0.6823	0.3125	0.6575	0.4286	0.7366	0.4375	0.7215	0.7460	0.6854	0.6458	0.5833

Table 9.3f: Machine Learning Results for Random State, RS, (65)

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
65	Random Forest	0.3651	0.6700	0.3750	0.6482	0.4127	0.7123	0.3542	0.6644	0.7143	0.7010	0.6458	0.57
65	SVC	0.4286	0.7266	0.3542	0.6661	0.4127	0.7467	0.3542	0.6917	0.7302	0.7524	0.6458	0.59
65	Logistic Regression	0.3333	0.6891	0.2708	0.6684	0.3651	0.6616	0.3750	0.6370	0.7619	0.7548	0.6667	0.63
65	Decision Tree	0.2857	0.5369	0.3125	0.5541	0.2857	0.5362	0.3125	0.5657	0.6190	0.5927	0.6042	0.54
65	K Neighbors	0.2857	0.5976	0.2292	0.5759	0.3651	0.6891	0.2500	0.6055	0.7460	0.7225	0.5625	0.54
65	Gradient Boosting	0.3651	0.6185	0.1875	0.5758	0.3651	0.6837	0.3125	0.6391	0.7778	0.7093	0.6458	0.60
65	Extra Trees	0.2698	0.6952	0.3542	0.6264	0.3651	0.7102	0.3958	0.6193	0.7143	0.7452	0.6458	0.60
65	MLP	0.3175	0.6046	0.2708	0.6295	0.3968	0.6713	0.4583	0.6686	0.7143	0.6890	0.5833	0.54
65	Forward Feed NN	0.3175	0.6046	0.2708	0.6295	0.3968	0.6713	0.4583	0.6686	0.7143	0.6890	0.5833	0.54
65	Backward Feed NN	0.4127	0.6634	0.3333	0.6714	0.4286	0.6854	0.3750	0.6679	0.7619	0.7978	0.6458	0.64

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
70	Random Forest	0.4921	0.7518	0.3750	0.7039	0.3651	0.7198	0.3958	0.6925	0.6349	0.7530	0.7708	0.83
70	SVC	0.4603	0.8130	0.4792	0.7687	0.4603	0.7924	0.4167	0.7463	0.7302	0.7548	0.7917	0.83
70	Logistic Regression	0.4286	0.7513	0.3750	0.7118	0.3968	0.7449	0.4167	0.7052	0.6984	0.7177	0.7917	0.83
70	Decision Tree	0.3968	0.6174	0.3750	0.5912	0.3492	0.5932	0.2708	0.5402	0.5714	0.5437	0.6875	0.68
70	K Neighbors	0.3651	0.7406	0.4167	0.6804	0.4444	0.7176	0.3958	0.6586	0.6667	0.6878	0.7500	0.77
70	Gradient Boosting	0.4286	0.7536	0.3750	0.6936	0.3492	0.7137	0.3125	0.7066	0.6508	0.7440	0.7917	0.83
70	Extra Trees	0.4444	0.7417	0.3958	0.7194	0.3492	0.6756	0.3125	0.6643	0.6667	0.7584	0.7083	0.83
70	MLP	0.4762	0.7607	0.3958	0.7032	0.4762	0.7409	0.4167	0.7035	0.5873	0.6926	0.7708	0.77
70	Forward Feed NN	0.4762	0.7607	0.3958	0.7032	0.4762	0.7409	0.4167	0.7035	0.5873	0.6926	0.7708	0.77
70	Backward Feed NN	0.4127	0.7108	0.3750	0.6992	0.4127	0.7436	0.3542	0.7117	0.6984	0.7464	0.7292	0.84

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
75	Random Forest	0.3968	0.7042	0.4583	0.6986	0.4444	0.7169	0.3125	0.6861	0.7619	0.8672	0.8125	0.8000
75	SVC	0.3492	0.7621	0.4167	0.7441	0.4127	0.7696	0.3750	0.7338	0.7460	0.8194	0.7708	0.8000
75	Logistic Regression	0.381	0.7381	0.3750	0.7130	0.4444	0.7527	0.3958	0.7190	0.6825	0.7943	0.7083	0.8000
75	Decision Tree	0.3175	0.5575	0.2708	0.5320	0.2222	0.5118	0.2292	0.5164	0.7302	0.7620	0.7083	0.6000
75	K Neighbors	0.4286	0.6518	0.5833	0.7650	0.3175	0.6835	0.3333	0.6707	0.7302	0.7117	0.8125	0.8000
75	Gradient Boosting	0.3492	0.6822	0.4167	0.7039	0.4444	0.7180	0.3125	0.6298	0.7302	0.7883	0.7917	0.8000
75	Extra Trees	0.4286	0.6795	0.3958	0.6984	0.3810	0.6994	0.3333	0.6678	0.7143	0.7709	0.7500	0.8000
75	MLP	0.3651	0.6908	0.3750	0.6429	0.3968	0.7049	0.2708	0.6236	0.6984	0.7990	0.7292	0.8000
75	Forward Feed NN	0.3651	0.6908	0.3750	0.6429	0.3968	0.7049	0.2708	0.6236	0.6984	0.7990	0.7292	0.8000
75	Backward Feed NN	0.3651	0.7216	0.4583	0.7189	0.4127	0.7517	0.3750	0.6995	0.7302	0.8230	0.7708	0.8000

		Multi-Class Classification								Binary Class			
		Mode Imputation				KNN Imputation				Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
80	Random Forest	0.4603	0.7725	0.4792	0.7849	0.3175	0.7096	0.2917	0.7177	0.7460	0.7996	0.7500	0.7500
80	SVC	0.3968	0.7712	0.3958	0.7769	0.3651	0.7912	0.5208	0.7696	0.7619	0.7811	0.7292	0.7292
80	Logistic Regression	0.3651	0.7525	0.3958	0.7362	0.3492	0.7642	0.2292	0.6655	0.7302	0.8038	0.7500	0.7292
80	Decision Tree	0.2698	0.5498	0.4167	0.6384	0.2540	0.5240	0.1875	0.4881	0.5873	0.5700	0.6458	0.5625
80	K Neighbors	0.3810	0.6742	0.4375	0.6898	0.3810	0.6992	0.4375	0.7045	0.6825	0.7315	0.6875	0.7292
80	Gradient Boosting	0.4127	0.7236	0.3958	0.7005	0.3016	0.6958	0.3333	0.6695	0.7302	0.8122	0.6875	0.7292
80	Extra Trees	0.4286	0.7224	0.5000	0.7593	0.3810	0.6849	0.3125	0.6994	0.7302	0.7972	0.7292	0.7302
80	MLP	0.4444	0.6864	0.3542	0.6707	0.3651	0.6750	0.3542	0.6469	0.6825	0.7787	0.6250	0.7407
80	Forward Feed NN	0.4444	0.6864	0.3542	0.6707	0.3651	0.6750	0.3542	0.6469	0.6825	0.7787	0.6250	0.7407
80	Backward Feed NN	0.4127	0.7053	0.5208	0.7643	0.4286	0.7302	0.3333	0.6776	0.7302	0.7883	0.6667	0.7292

		Multi-Class Classification				KNN Imputation				Binary Class			
		Mode Imputation								Mode Imputation			
		80:20		70:15:15		80:20		70:15:15		80:20		70:15:15	
Random State	ML Model	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance	Accuracy	AUC Performance
	Best Results	Random Forest, RS 70 0.4921	SVC, RS 70 0.8130	K Neighbors, RS 75 0.5833	Random Forest, RS 80 0.7849	Random Forest, RS 80 0.4921	SVC, RS 80 0.7912	SVC, RS 80 0.5208	SVC, RS 80 0.7696	Logistic Regression, RS 42 0.8571	Backward Feed NN, RS 42 0.8971	Random Forest, RS 50 0.8750	Backward Feed NN, RS 50 0.9071

*Best results for Accuracy are highlighted in green and best AUC performance are highlighted in yellow.

Multi-Class Classification (MCC) Model Results

For MCC, at 80:20 splitting ratio, Random Forest (RS 70) using Mode imputation with Significant Features dataset emerged as the best performing model with **49.21%** accuracy. SVC (RS 70), using Mode imputation with Significant Features dataset, with **81.30%** accuracy was best performing model by AUC. *See Table 9.3j.*

Still for MCC, at splitting ratio 70:15:15, KNeighbors (Random State 75) employing Mode imputation for significant features, was the best performing model with **58.83%** Accuracy. Random Forest (at RS 80) employing Mode imputation for significant features, was the best performing model with **78.49%** AUC performance.

Overall, the best performing model for MCC by Accuracies was KNeighbors (RS 75) employing Mode imputation for significant features with splitting ratio 70:15:15 (having accuracies **58.83%**), and the best performing model for MCC by AUC accuracies was SVC (Random State 70) using Mode imputation with Significant Features dataset (having accuracies of **81.30%**).

Results from the experiments shows that while accuracy measures are low in multi-class classification, AUC performance measures are high. This is not uncommon in a multi-classification of this nature (Metzner et al., 2022). Accuracy reflects the proportion of correct predictions over total predictions. While this approach is simple, intuitive and best for balanced datasets, it can be misleading where the dataset is not balanced, thus, failing to reflect a model's confidence or ranking ability (Delovski, 2023). On the other hand, AUC-ROC measures a model's ability to distinguish between classes (ranking quality) (Richardson et al., 2024). It captures a model's performance across all classification thresholds, and it is robust to class imbalance (McDermott et al., 2024). Its shortcoming is that it may be less interpretable in a

multi-class setting and not easy to explain to non-technical stakeholders (Wang, 2024), however, the reliability it affords makes up for these limitations. Also, accuracy is affected by label frequency, but AUC accuracy is not because it ranks each class independently and then aggregates (Richardson et al., 2023).

Additionally, the difference in the Test and AUC accuracies suggest that the models are good at ranking the true class higher than others but struggles to assign the correct final label, possibly due to class imbalance, overfitting to training data and/or sub-optimal threshold selection (Powers, 2020).

Therefore, according to the critical decision rule when working with imbalanced dataset, AUC-ROC is generally a more reliable indicator of a model's true performance than accuracy (Fawcett, 2006; Saito & Rehmsmeier, 2015). For instance, in Table 9.3, at Random State 70 (Mode imputation for significant features dataset), SVC has an Accuracy of **46.03%** and AUC Accuracy of **81.30%**, indicating a strong underlying class separation ability. The low accuracy value suggests low threshold sensitivity and label imbalance while AUC with higher performance value offers a more dependable view of generalised performance.

Binary Classification (BC) Model Results

BC findings for splitting ratio 80:20 shows Logistics Regression (RS 42) employing Mode imputation for significant features dataset was the best performing model with an accuracy of **85.71%**. BFNN (RS 42) employing Mode imputation for Significant dataset features was the best performing model with **89.71%** accuracy.

For splitting ratio 70:15:15, Random Forest (RS 50) employing Mode imputation for Significant features dataset is the best performing model, having **87.50%** accuracy while for AUC performance, BFNN (RS 50) employing Mode imputation for Significant features dataset was the best performing model with **90.10%**.

Lastly, for BC with KNN imputation, at splitting ratio 80:20, MLP and FFNN (both at RS 45) emerged as best accuracy models with measures of **87.30%** each while SVC (RS 50) emerged as the best AUC model with a performance of **86.84%**. At splitting ratio 70:15:15, Gradient Boosting (RS 50) emerged as the best model by accuracy, having a measure of **91.76%** while KNeighbors (RS 50) emerged as the best model by AUC with a performance of **92.42%**. *See Table 9.3j*

Unlike the wide discrepancy between Accuracy and AUC performance in MCC, the differences in BC Accuracy and AUC performance are much closer (**85%-92%**). This shows that the models are both assigning class labels correctly and ranking predictions by confidence are well calibrated, indicating an ideal and reliable outcome that simplifies reporting and interpretation (Fawcett, 2006; Powers, 2020).

Since the goal of this study is to identify the most suitable algorithm (model), with highest correct predictions among the most commonly identified ones, in predicting factors that favour OSC adoption in the UK, both accuracy and AUC measures are sufficient for BC in the case of the study and within the limits of the data used. While the accuracy allows easy interpretability of the results, AUC performance provide higher reliability, sensitivity/specificity and threshold tuning where it matters.

Summarily, in binary classification tasks, especially with a balanced class distribution, accuracy remains a valid and interpretable performance metric (Thölke et al., 2023). However, AUC performance are often preferred in imbalance tasks because it evaluates performance across all thresholds and does not depend on a single decision point (Powers, 2020; Saito & Rehmsmeier, 2015). Since both metrics relatively agrees in this study, with an average difference of $\pm 0.5\%$ in most cases, this implies the BC models are well-calibrated and generalises well, and both can be used for decision making. It should be noted that since accuracy is not usually guaranteed on unseen data, and AUC remains almost constant irrespective of newness of data, it is often considered ahead of accuracy in model development.

9.1.5 Selecting the Best Models

Following the good AUC performances observed in the multi-class classifications, and the high values for both accuracy and AUC performance in Binary Classification (highlighted in green and yellow respectively in Table 9.3), the best performing algorithms were checked for possible overfitting instances by comparing the evaluation measures across training, (validation) and testing. Below is an extract of the best models' details from each experiment.

Table 9.4a: Detailed Performance of models with high Accuracy (Multi-Classification, Mode Imputation, Splitting Ratio 80: 20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test Score	F1	Accuracy	AUC Performance
70	Random Forest	1	1	1	1	1	{'2': 76, '3': 58, '5': 42, '1': 41, '4': 35}		0.3934	0.4407	0.4064		0.4921	0.7518

Table 9.4b: Detailed Performance of models with high AUC performance (Multi-Classification, Mode Imputation, Splitting Ratio 80: 20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test F1 Score	Accuracy	AUC Performance
70	SVC	0.7509	0.6643	0.6803	0.7063	0.9326	{'2': 76, '3': 58, '5': 42, '1': 41, '4': 35}		0.4978	0.4118	0.4114	0.4603	0.9326

Table 9.4c: Detailed Performance of models with high accuracy (Multi-Classification, Mode Imputation, Splitting Ratio 70:15:15)

Ran dom State	Model	Trai n Prec ision	Train Recall	Train F1 Score	Train Accur acy	Train AUC	Train Support		Val Precisio n	Val Recall	Val F1 Score	Val Accura cy	Val AUC	Val Support		Test Precision	Test Recall	T F S
75	K Neighb ors	0.5638	0.5317	0.5404	0.5455	0.8614	{'2': 66, '3': 51, '5': 36, '1': 36, '4': 31}		0.266	0.2795	0.2627	0.2766	0.5472	{'2': 14, '3': 11, '5': 8, '1': 7, '4': 7}		0.5983	0.5503	0.6

Table 9.4d: Detailed Performance of models with high AUC performance (Multi-Classification, Mode Imputation, Splitting Ratio 70:15:15)

Rando m State	Model	Train Precisio n	Train Recal l	Trai n F1 Scor e	Train Accurac y	Trai n AU C	Train Suppor t		Val Precisio n	Val Recall	Val F1 Score	Val Accurac y	Val AUC	Val Suppor t		Test Precisio n	Test Recall	Test F1 Score
80	Rando m Forest	1	1	1	1	1	{'2': 66, '3': 51, '5': 36, '1': 36, '4': 31}		0.3236	0.3049	0.3001	0.3404	0.7057	{'2': 14, '3': 11, '5': 8, '4': 7, '1': 7}		0.4634	0.4477	0.444

Table 9.4e: Detailed Performance of models with high Accuracy (Multi-Classification, KNN Imputation, Splitting Ratio 80: 20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test F1 Score	Accuracy	AUC
60	Random Forest	1	1	1	1	1	{'2': 76, '3': 58, '5': 42, '1': 41, '4': 35}		0.5347	0.4657	0.4811	0.4921	0.7

Table 9.4f: Detailed Performance of models with high AUC performance (Multi-Classification, KNN Imputation, Splitting Ratio 80: 20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test F1 Score	Accuracy	AUC
80	SVC	0.8044	0.7192	0.7454	0.75	0.9282	{'2': 76, '3': 58, '5': 42, '1': 41, '4': 35}		0.4185	0.3191	0.3088	0.3651	

Table 9.4g: Detailed Performance of models with high accuracy (Multi-Classification, KNN Imputation, Splitting Ratio 70:15:15)

Ran dom State	Model	Trai n Prec ision	Train Recall	Train F1 Score	Train Accur acy	Train AUC	Train Support		Val Prec ision	Val Recall	Val F1 Score	Val Accur acy	Val AUC	Val Support		Test Prec isio n	Test Recall	Test Score
80	SVC	0.8206	0.7432	0.7683	0.7682	0.9479	{'2': 66, '3': 51, '5': 36, '1': 36, '4': 31}		0.5073	0.3477	0.3529	0.3830	0.7664	{'2': 14, '3': 11, '5': 8, '4': 7, '1': 7}		0.7146	0.4476	0.473

Table 9.4h: Detailed Performance of models with high AUC performance (Multi-Classification, KNN Imputation, Splitting Ratio 70:15:15)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Val Precision	Val Recall	Val F1 Score	Val Accuracy	Val AUC	Val Support		Test Precision	Test Recall	Test Score
80	SVC	0.8206	0.7432	0.7683	0.7682	0.9479	{'2': 66, '3': 51, '5': 36, '1': 36, '4': 31}		0.5073	0.3477	0.3529	0.383	0.7664	{'2': 14, '3': 11, '5': 8, '4': 7, '1': 7}		0.7146		0.4

Table 9.5a: Detailed Performance of models with high accuracy result (Binary Classification, Mode Imputation, Splitting Ratio 80:20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test F1 Score	Accuracy	AUC Performance
42	Logistic Regression	0.7193	0.5325	0.6119	0.7937	0.8299	{0: 175, 1: 77}		0.8125	0.6842	0.7429	0.8571	0.8299

Table 9.5b: Detailed Performance of models with high AUC performance (Binary Classification, Mode Imputation, Splitting Ratio 80:20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test F1 Score	Accuracy	AUC Performance	AUC
42	Backward Feed NN	1	1	1	1	1	{0: 175, 1: 77}		0.7647	0.6842	0.7222	0.8413	0.8971	{0: 175, 1: 77}

Table 9.5c: Detailed Performance of models with high accuracy result (Binary Classification, Mode Imputation, Splitting Ratio 70:15:15)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Val Precision	Val Recall	Val F1 Score	Val Accuracy	Val AUC	Val Support		Test Precision	Test Recall	Test F1 Score
50	Random Forest	1	1	1	1	1	{0: 153, 1: 67}		0.6	0.2143	0.3158	0.7234	0.8009	{0: 33, 1: 14}		0.8462	0.7333	0.7857

Table 9.5d: Detailed Performance of models with high AUC performance (Binary Classification, Mode Imputation, Splitting Ratio 70:15:15)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Val Precision	Val Recall	Val F1 Score	Val Accuracy	Val AUC	Val Support		Test Precision	Test Recall	Test F1 Score
50	Backward	1	1	1	1	1	{0: 153, 1: 67}		0.6364	0.5	0.56	0.766	0.7597	{0: 33, 1: 14}		0.7059	0.8	0.75

Table 3.5c. Detailed Performance of models with high accuracy result (Binary Classification, KNN Imputation, Splitting Ratio 80:20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test F1 Score	Accuracy	AUC Performance
45	MLP	1	1	1	1	1	{0: 175, 1: 77}		0.8235	0.7368	0.7778	0.8730	0.8313
45	Forward Feed NN	1	1	1	1	1	{0: 175, 1: 77}		0.8235	0.7368	0.7778	0.8730	0.8313

Table 9.5f: Detailed Performance of models with high AUC performance (Binary Classification, KNN Imputation, Splitting Ratio 80:20)

Random State	Model	Train Precision	Train Recall	Train F1 Score	Train Accuracy	Train AUC	Train Support		Test Precision	Test Recall	Test F1 Score	Accuracy	AUC Perfo
50	SVC	0.8769	0.7403	0.8028	0.8889	0.9567	{0: 175, 1: 77}		0.6923	0.4737	0.5625	0.7778	0.868

Table 9.5g: Detailed Performance of models with high accuracy (Binary Classification, KNN Imputation, Splitting Ratio 70:15:15)

Rando m State	Model	Train Precisio n	Train Recal l	Train F1 Score	Train Accurac y	Train AUC	Train Suppor t		Val Precisio n	Val Recal l	Val F1 Score	Val Accurac y	Val AU C	Val Suppor t		Test Precisio n	Test Recal l	Test F1 Score
50	Gradien t Boostin g	0.9706	0.985 1	0.977 8	0.9864	0.997 2	{0: 153, 1: 67}		0.5833	0.5	0.538 5	0.7447	0.68 4	{0: 33, 1: 14}		0.8667	0.866 7	0.866 7

Table 9.5h: Detailed Performance of models with high AUC performance (Binary Classification, KNN Imputation, Splitting Ratio 70:15:15)

[illegible]

While five (5) models (see tables highlighted with green and cyan colours) exhibited improvement in accuracies and AUC values over training/(validation)/test, it emerged that only LR (at Random State 42) employing Mode imputation for Significant features, in a binary class experiment using a splitting ratio 80:20, having an accuracy of **85.71%** and **AUC of 84.69%** displayed no form of overfitting across all its metrics. It is therefore recommended as the most suitable ML model for the task of predicting OSC adoption likelihood on a proposed construction project in the UK based the data used in this thesis.

With the findings documented in this section, the five objectives of this thesis are satisfied, the research questions are answered and consequently the aim of the study achieved. The next section discusses the findings.

9.2 DISCUSSION

The global construction industry is at a critical juncture, facing escalating challenges such as productivity stagnation, environmental degradation, increased safety challenges among others, owing to inherent limitations of the dominant traditional construction methods. The continuous population rise in recent years further puts pressure on the industry to provide shelter in meeting the growing population. For instance, the world population, which was 6.162 billion people in 2000 (DataCommons, 2025), stands today at approximately 8.2 billion (Worldometer, 2025b), indicating a 33.07% growth. It is expected to hit 9.8 billion by 2050 (United Nations, 2024).

Similarly, the United Kingdom construction industry is struggling with ageing work force, conservatism, protectionism, slow growth, having to adapt to advancements in technology amidst other challenges. The UKCI has not been able to meet its housing provision targets for more a decade (*to be conservative with figures*). The UK has equally had its fair share of sprawling population. The United Kingdom (UK) population which was 67.35 million in 2020; today, it is about 69.45 million (Worldometer, 2025b), indicating a 3.11% growth over the 2020 population. It is expected to stretch beyond 71.27 million people by 2030 (a 2.62% growth) and reach for 75.5 million by 2050, indicating a 5.94% growth (Bacci, 2017; UN, 2021; Worldometer, 2025a). Interestingly, population growth and the need for shelter are siemens twins. As population growth always require a corresponding shelter provision which many nations have not been able to balance together.

Efforts have been made using traditional brick and mortar and other conventional construction approaches in creating the required balance for housing provision, but this approach has not only fallen short of meeting the targets, it has also enormously increased carbon emission, leading to many environmental concerns. Interestingly, over the years, the traditional

construction methods (*which is used interchangeably with conventional construction method in this thesis*) have been associated with monumental records of time loss, accidents, and high project costs, mostly end up with cost over-run (Barton & Wilson, 2023, 2023; Perry et al., 2021).

Offsite construction concept, a variation of Modern Methods of Construction has been globally adjudged as an approach that can address the shortcoming of the traditional construction approach if widely adopted. Reports have it that countries are now fast looking in the direction of OSC both to increase their housing provision and to address environmental challenges. For example, Denmark increased its OSC usage by 40%, Sweden, Netherlands, Germany by 15% and Austria by 33% (Jiang et al., 2020). China planned reaching 60% urbanisation in 2020 using OSC (Jiang, et al., 2020b), Japan produces 150,000 houses per annum using OSC (Zhai et al., 2014) while Singapore used OSC to provide shelter for over 80% of her urban population (Shang et al., 2020). Honk Kong piloted about 65% of its construction projects with OSC as of 2005 (Jiang, et al., 2020b). Malaysia has considered a 84% and 60% use of OSC in government and private projects respectively (Azalea, 2023). The United States of America and Canada have approximately 5% of OSC for all types of buildings (Broadhead et al., 2023). Australia has about 3% of its construction works being OSC (Hosseini et al., 2018). Studies show that OSC is yet to be adopted in many construction works in Africa (Kolo et al., 2014; Rahimian et al., 2017). The UK is struggling to achieve 10% OSC usage on her projects.

Though the UK had a fair share in the number of OSC usage during its initial emergence as prefab houses, it cannot be said today that the UK had extensively adopted OSC as a construction technique, following reports that a larger percentage of its entire construction

projects still employ traditional construction method (Blismas & Wakefield, 2009). The UK has been struggling to meet its housing targets for over a decade (ConstructionNews, 2024; House of Lords, 2022; Savills, 2024). The UK is struggling to produce 150,000 houses in a year when they actually need to produce 340,000 (LetsBuild, 2023). OSC has been explored as an alternative to the slow pace traditional construction in the UK, but its uptake has been very challenging (UK Parliament, 2024a). Scholars have approached OSC adoption challenges from different views (*See Chapters 2 and 3*), but their efforts seem not to hit the targets the UK government desires (Brown, 2024; Ridings, 2024; UK Parliament, 2023). This research therefore took a closer examination at OSC adoption issues in the UK, from perspectives other than those commonly reported, in identifying the critical factors influencing OSC adoption.

It commenced with a search for globally reported OSC adoption factors, amidst other conditions like the research approach employed in addressing OSC low adoption, the methods used, the type(s) of analysis conducted, the theoretical underpinnings considered, industry guides, and the like. It proceeded to finding out which of these global factors applies to the UK context through interviewing UKCI professionals. The study triangulated the qualitative findings with a UK-specific SLR and developed a survey questionnaire from that operationalisation. The survey gathered quantitative OSC project data for feature selection of most critical factors influencing OSC adoption in the UK and to develop an OSC adoption predictive model using machine learning, employing numerous and rigorous approach and experiments. *See Chapter 7 and 8.*

9.2.1 Critical OSC Influencing Factors to UKCI

From the study experiments using rigorous feature selection method, the most critical factors, common to both multi-class classification and binary classification (*Refer to Sections 7.2 and 9.1.4*), influencing OSC adoption in the UK are:

1. Awareness of planning authorities, i.e., how the knowledge level of planning authorities on Offsite Construction (OSC) construction methodologies influences their decision to approve the project, **AW4**.
2. Design lead time (Is the amount of time required before freezing OSC design quicker or slower), **DCF1**.
3. Scalability (Repeatability of design and project modules), **DCF10**.
4. Availability of past OSC Project Data to support adopting OSC for the project **PKD2**.
5. Monotonous perception -A common misconception that OSC is limited to box-like designs and unsuitable for creative or flexible architectural solutions, **PP5**.
6. Availability of Road width that fits truck size **SCL7**.
7. Access Road to the site that fits truck size, **SCL8**.
8. Site Hedging (Availability of site storage area for components and modules), **SCL11**.

1. Awareness of planning authorities, AW4: The question asked here was *‘Awareness of planning authorities: To what extent was the knowledge level of planning authorities concerning Offsite Construction (OSC) construction methodologies influences their decision to approve the project?’* It emerged from the rigorous feature selection experiments for both multi-class and binary classification that the knowledge level of planning authorities’ officials

responsible for approving the construction of buildings play a critical role on how OSC is considered for proposed project. Where they appear not to have sufficient knowledge or awareness of OSC methodologies, that can impair quick approval process of OSC designs. Extant studies, academic and industry reports (Olayiwola et al., 2025; Pan et al., 2008), heavily decry the current construction approval process, highlighting it as a major impediment to general construction developments. Studies that have looked at factors affecting OSC adoption also reported planning approval process as a major impediment to wider OSC uptake (Arif et al., 2017a; Jin et al., 2018; Miles, 2021; Pan et al., 2007a; Wuni & Shen, 2020a, 2023; Yang et al., 2019). They however failed to spot what the real issues with approval process is.

This study's SLR findings unveils that the re-emergence of OSC defies the conventional approach of Start-to-Finish construction process and traditional structured outline of the building (and approval) process. The interview analysis of this study added that the current frameworks used for approval does not yet fully accommodate the use of OSC for building projects. Wusu, et al., (2025) reported in a qualitative evaluation of OSC awareness issues in the UK that allied UKCI stakeholders, of which planning authorities' officials are a part, are not duly aware of OSC concept like the core industry professionals are. The study highlighted lopsided awareness as a major OSC awareness challenge in the industry and noted the re-emergence of OSC concept is not yet fully captured in the RIBA-PoW approval checklist. Thus, the re-emergence of OSC may only add to the bottlenecks of approval process if OSC knowledge is not adequately communicated to planning officials. If the planning approval framework(s) is not updated to cater for OSC designs and construction process which, for example, may not require columns and slab stage approvals and may not reflect in designs,

there will be a delayed take-off of on-site assemblage, resultantly discouraging use of OSC for projects.

In summary, while studies on OSC have noted the obstructing role of planning authorities in the adoption of OSC for projects, this study adds specificity to the inhibiting role the planning authorities play in the wider adoption of OSC by bringing to the fore, the probable major cause- their lack of OSC awareness. This study unveils limited OSC knowledge amidst the planning authorities/sector and argues that their knowledge level may be responsible for the slow approval rate of OSC projects, thus, discouraging the design or recommendation of OSC design for construction projects. This finding aligns with both ADKAR and C-BAM theoretical views.

2. Design lead time, DCF1: This is the amount of time required before freezing OSC design. Once the design is freeze, and procurement commences, there may be no room for changes. However, freezing the design also puts a cap on the budget, as no changes may imply no variations. This factor emerged as one of the critical factors influencing OSC adoption in the UK. In the context of the phrase ‘quicker or slower’ lead time attempts to encapsulate industry stakeholders’ perception of how swiftly detailed design must be completed to initiate module fabrication.

Findings from the SLR showed perceived constrains around accelerated design timelines can present significant barriers to OSC adoption. Many UKCI professionals are accustomed to flexible iterative design processes associated with traditional construction. The shift to OSC requires a front-loaded design process, demanding rigorous coordination among the design team and supply chain partners early on the project. This requires a design team with good knowledge of DfMA, an attribute quite scarce among present crop of designers. Design quick

freeze challenges existing workflows and may discourage OSC consideration for projects, especially in organisation lacking the ‘necessary’ DfMA technical capacity to support early-stage design integration.

Conversely, studies have reported long lead time to freeze OSC designs (Bendi, 2020a; Luo et al., 2020), perhaps owing to lack of adequate DfMA knowledge amidst other factors. The long lead time thus negate the timesaving driving attribute of OSC. While quicker design lead time can sometimes be a driver for OSC consideration for projects because it offers predictability and cost efficiency when effectively managed, a long lead time can be a discouragement as it results in time loss.

Therefore, as (Goulding & Rahimian, 2019a, 2019b) suggested, clients, designers and contractors need to integrate design planning and digital tools, make specifications clearer to reduce rework and improve delivery speed in OSC projects in the UK. Conclusively, the criticality of a design lead time on OSC project is a function of how well the stakeholders adapt their processes to front-load design input early in the project lifecycle. This aligns with the issues of concerns and level of use as noted in C-BAM theory.

3. Scalability-Repeatability of design and project modules, DCF10: Scalability has been largely discussed by extant literature as a driver of OSC adoption. It refers to the ability to standardise and replicate design components or modular units across different projects with minimal reconfigurations. This OSC attribute is foundational to the cost-efficiency, speed and predictable benefits OSC is often associated with. In the UK context, (Pan & Sidwell, 2011), modular elements repeatability represents a paradigm shift in project delivery models and enables economies of scale by reducing the need for bespoke designs, allowing manufacturers

to mass-produce components with higher precision and better tolerances. This characteristic is particularly invaluable in large-scale residential or institutional housing projects where standardisation can significantly reduce both design time and construction wastes but can be disadvantageous in bespoke designs and challenging where aesthetic flexibility is a demand. This inability of scalability to adapt to flexible aesthetic and bespoke design was a debate during the interview. The interview analysis highlighted two perspective on scalability. A school of thought sees it as bringing monotony and lack of creativity to building designs, the second argues that the modules can be creatively arranged in a number of forms that can communicate rich and ingenious architectural master pieces. What both ideologists did not refute is the driving attribute it impacts on OSC adoption. This aligns with the issues of concerns and level of use as noted in C-BAM theory.

The human tendency to be swayed by perception over data is particularly evident in the field of modern methods of construction (MMC). MMC has often been accompanied by an idiosyncratic agenda about aesthetic, not helped by childhood memories of prefabricated classrooms. Similarly, the mention of ‘standardisation’ as part of the narrative around product platforms has sparked concerns that our future homes and built environment will be devoid of vernacular charm. Despite our best efforts at Akerlof to demonstrate that MMC is not anathema to character and beauty, our voice has struggled to reach the ears of popular opinion (Stein & ConstructionNews, 2025).

4. Project Data to support adopting OSC for the project, PKD2: Paucity of OSC project data has been reported in many studies and across many regions as a major barrier to OSC adoption (H+H Ltd, 2024; Saad, et al., 2023; Wuni & Shen, 2023; Wusu, et al., 2025). While countries like Japan, have increased their use of OSC through coordinated project data (Oti-

Sarpong et al., 2022a; Steinhardt & Manley, 2016), the UK is still struggling to collate OSC project data (Ridings, 2024; UK Parliament, 2023). This research finding identifies the unavailability of project data to support OSC adoption as a very critical factor influencing OSC adoption in the UK. A recent study by Wusu et al., (2025), inspired by the House of Common written evidence (UK Parliament, 2024 and Ridings, 2024), confirmed through notable building regulation organisations in the UK that there is no database for OSC projects in the UK.

Wusu et al., (2025) buttresses Steinhardt and Manley, (2016) which submitted that ***“Specific data on the size of the UK prefabricated housing market is not readily available. Centrally coordinated collections have not typically identified methods of construction for new construction. The exceptions to this are the English Housing and Housing Condition Surveys (Department for Communities and Local Government, 2010, 2013) which have reported that ‘traditional construction’ housing, predominantly masonry, has accounted for at least 95% of all dwellings since 1990. The remainder of ‘non-traditional construction’ also does not solely capture prefabrication and covers both in-situ fabrication of concrete and metal framing. In the UK, prefabricated construction is grouped under the larger banner of ‘Modern Methods of Construction’ (MMC), which largely consists of ‘offsite’ methods. Estimates of use across the entire construction sector (residential, non-residential, civil) have ranged from 2% in 2007 (Goodier & Gibb, 2007), to 7% in 2010 (Taylor, 2010).”*** While experiments, case studies, document analysis have immensely contributed to how far OSC adoption has come, they do not suffice for the right amount and type of data required to drive OSC adoption to the desired success.

Further, absence of adequate OSC project data technically implies absence of right OSC knowledge. Availability of OSC project data would provide the required stability for OSC adoption predictability and reduce instances of misleading adoption reports, adoption prediction or projection failures.

Some of the issues associated with collating OSC project data from the SLR and interview analyses are limited availability of project data, insufficiency of project information data, incompleteness and inaccuracy of collated data and poor management of project data (L. Luo et al., 2020) and lack of robustness in the data quality (An et al., 2020) to mention a few. The dissonance created by unavailability of collated and coordinated data on OSC emergence and trends creates a vacuum that leads to loss of huge investments in millions of Pounds or Dollars, and failed projects. The pains and disappointment that come with such failures impedes OSC wider adoption (Alhawamdeh & and Lee, 2024; Ngoc Nguyen et al., 2020).

Unfortunately, what we have today are studies on OSC that are not driven by real or substantial project data. Hence, this study attempted the critical factor synthesis/identification and predictive model development with executed or considered OSC project information.

Existing OSC policies appears to have been built on sparse, uncoordinated, subjective, anecdotal (Bendi, 2020a) or ethnographic datasets (Zhou et al., 2021b) further informing poor OSC understanding. This may never drive the OSC concept forward as required, nor its adoption as desired (Wusu et al., 2025). The revolutionary change desired in OSC may not happen anytime soon without adequate attention to the availability of (real-time) OSC project data and a co-ordinated management of same (Steinhardt & Manley, 2016). Only genuine data on OSC projects can help improve OSC concept and process, and drive wider adoption through

creating OSC adoption insight, providing OSC business intelligence and informed OSC policies (UK Parliament, 2023; Wusu, et al., 2025).

The absence of coordinated collated data creates a lack of transparency on the issues relating to OSC adoption as can be seen in the divergent view submitted by scholars (Wusu, Alaka, Oseghale, Yusuf, Sunmonu, & Akinyemi, 2025). The failure to aggregate project data equally creates a worry for investors and policy makers on the future of OSC (Ridings, 2024).

A way forward to surmount the limitations of wider OSC adoption and ace an unprecedented growth in OSC adoption is through OSC project metrics. Decisions of wider adoption of OSC cannot continue to be based on wishful thinking, and a way to overcome that is to use proper project data. The existence of OSC database would create a better way to visualise and keep track of OSC evolution and progress. It would also connect OSC policy, planning, design, execution, and business as seen in C-BAM's innovation configuration map. A step towards to addressing the unavailable OSC project data critical factor is therefore proposed for this study as shown below.

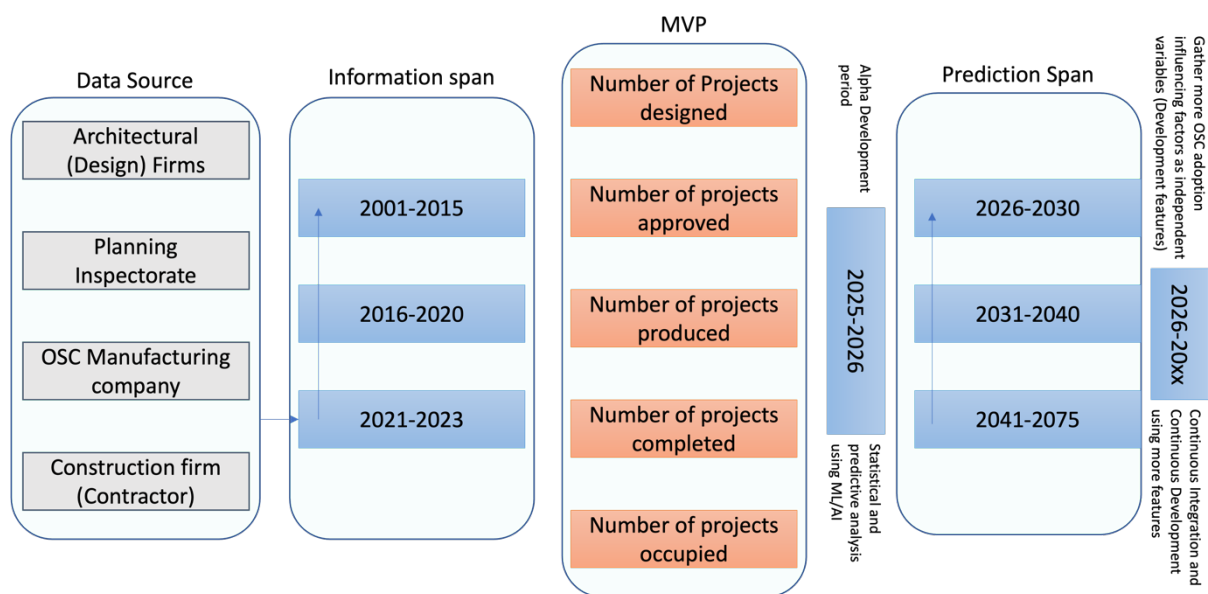


Figure 9.1: Possible approach to addressing OSC data collection.

Source: Wusu et al., (2025)

5. Availability of Road width that fits truck size (SCL7): Most OSC manufacturing factories are located quite far away from in some remote areas, requiring modules or components to be transported to point of use (Gan, 2018). Roads are therefore an integral factor in promoting development and a major factor in economic growth and general logistics. The availability of roads to raw material, production factories and distribution of finished products is integral to OSC business success. In the context of OSC which requires transportation of large, prefabricated modules to site, roads, which often are less than or approximately equal to module widths, directly impact delivery feasibility. Many UK urban areas, especially cities like London, Manchester have narrow or congested roads that are not so supportive with the turning radius and width requirements of delivery trucks or modular transport vehicles.

Roads with inadequate widths contribute to health and safety risks for OSC projects. It results in traffic jam and manoeuvring restricted spaces increases accident likelihood. It equally draws concerns from municipal authorities and requires additional permits (Blismas et al., 2005).

BuildOffsite, (2020) and Arif et al., (2017) highlighted the challenges of moving large modules through constrained urban routes can lead to re-routing, offloading to smaller vehicles, outright delivery refusal or architectural redesigning (Gan, 2018). This significantly impact cost and may result in delays. Widening such roads or providing dedicated logistics routes to construction sites can help reduce this disruption.

6. Access Road to the site that fits truck size, SCL8: Aside the UK having narrow roads, access roads to site has been described as a major limitation to wider OSC uptake. This factor has to do with site ingress- accessing the project site from public routes. While some green field projects may enjoy creating quick roads to project site, in-fill, and brown field developments in the UK, especially in urban regeneration or retrofitting projects, site boundaries are constrained by surrounding buildings, utilities or terrain.

Blismas et al., (2005) and Goulding et al., (2014) reported that restricted site access can negate the time and efficiency of OSC gains. Without an adequate delivery turning zone, unloading space and hardstanding for heavy vehicle operations, modules may be delayed, damaged or require additional lifting operation. This reduces the value proposition of OSC in the immediate or long-term. Ajayi et al., (2019) noted that such damages account for about 10% of damages reported in OSC. Moreso, inadequate access undermines the benefits of Just-in-Time (JIT) delivery concept.

SCL 7 and 8 underscore the importance of SCL factor as a non-negotiable enabler for effective OSC implementation. In the UK context of dense urban planning, legacy infrastructure and narrow accessways, failing to account for these can lead to adoption hesitancy among contractors and clients- reinforcing the necessity of early-stage logistics audit during project planning.

7. Site Hedging (Availability of site storage area for components and modules), SCL11: Site hedging is a critical logistical factor in the successful implementation of OSC, particularly in a space constrained location. SCL 7 and 8 addresses how to get the modules to site, but SCL11 addresses where to keep the modules safely and securely, even if temporarily, before

they are assembled in their proper places of use. While the Just-In-Time (JIT) delivery principle is often used in OSC to minimise onsite storage, congestion and such associated costs (Pan & Goodier, 2012), particularly UK urban areas where most OSC projects sites are, it is not all projects that it works for. Furthermore, in a constrained access scenario, modules may need be delivered out-of-sequence or hedged temporarily in/out of site to ensure assemblage progresses as scheduled. Lack of storage space options results in inefficiencies for OSC project flow, making hedging issues a major barrier as reported by most studies (Zhai et al, 2018; Zhang et al, 2021).

8. Monotonous perception, PP5: The issue is from perception construct. It is the view that designs for OSC would usually be dull, boxy repetitive building that lack flexibility or aesthetic qualities. Stemming from post-war prefab housing and early modular typologies that prioritised speed over design innovations (Blismas et al., 2005; Goodier et al., 2019), the perception has long plagued OSC in the UK. The interview conducted debunked this perception, arguing that design outcome using modular concept is a function of the creativity of the designer and the project goal, not necessary because modules usually in a box shape- and they do not have to be boxes (Oti-Sarpong et al., 2022a). The quantitative approach however still identifies this as critical factor that undermines the confidence of client and investors, and one that planners and developers may resist (in urban or conservation areas) owing to concerns about visual integration and one that may deter professionals engaging with OSC- reinforcing their argument that OSC is an approach lacking aesthetic innovations in a world advancing in visually appealing developments. This again is a call for a mindset shift in the wider adoption pursuit of OSC employing change management model like ADKAR, where displaying successful, aesthetically mesmerising and structurally stable OSC project can further create

awareness on OSC flexibility in design (Wusu, Alaka, Oseghale, Yusuf, Sunmonu, & Akinyemi, 2025). *Refer to Section 10.1.2 and Figure 10.1*

9.2.2 Machine Learning Outcome

Following the findings highlighted above, identifying the best models based on accuracy and AUC performance and identifying models that exhibited consistent improvements across all parameters that can be deployed in real world applications, this study also spotted some characteristics from the result tables that add to various on-going ML discourse.

First, while the random state (RS) number 42 was made famous by Douglas Adams (1979) in the book "The Hitchhiker's Guide to the Galaxy", where it was humorously declared as "the answer to life, the universe, and everything." and has been set as the base random state in most coding languages, especially Python (Raschka & Mirjalili, 2019). There is not any mathematically proven or statistically accepted perspective (Scikit-learn, 2024) to this. It should not be regarded as the 'best' or the 'only' available RS in model development but a conventionally used RS by many data scientists (Adam, 1979; Geron, 2019). Following the identified best performing models and the deployable model, this study found that RS 42 does not always produce the best performance and so, should be adjusted or experimented with in a given/proposed task (Geron, 2019; Raschka & Mirjalili, 2019). As can be seen from the result experiment, RS 42 emerged only once in best accuracy and AUC results, i.e., 2 out of 16.

Geron, (2019) and Raschka & Mirjalili (2019) further argued that if a model performs well with multiple random states, it is likely stable. However, if results vary significantly across different random states, it suggests that the model is not stable and further tuning or feature selection refinement may be needed. Drawing from the various best-performing models from

the various experimental approaches (missing value imputation, splitting ratio and feature selection groups), using different random states for experimentation shows that the models have a tendency to perform better in real life based on the close range of the RS values results. This also indicate better stability at such values. For example, in this study, multi-class experiments showed more stability (better performance) at RS values above 60 while binary classification showed more stability (better performance) at RS values of 42 (the default state). Therefore, using different RS values present variations in performance and experimenting with multiple random states would be a good practice in model development.

Therefore, satisfying most of the ML development principles and guidelines, and in line the objective 5 and the study aim, the research identified a Logistics Regression model, RS 42 with **85.71%** accuracy and **84.69%** AUC performance from Binary Classification exercise as suitable for predicting OSC adoption likelihood for proposed construction projects in the UK within the limits of the study.

The best model found equally suggest that, within the limits of the data used for this study, Binary Classification is better suiting to predicting OSC adoption in the UK than Multi-Class Classification. This view agrees with the AI/ML construction related doctoral studies of Balogun, (2024) and Egwim, (2024) who exclusively used Binary Classification to predict building deconstruction and project delay respectively.

10.0 CONCLUSION

Chapter Overview

This chapters gives a broad overview of the background of this study and its intentions to identify the critical OSC influencing factors in the UK. It focused on drawing a conclusion based on the results that have been achieved in this study according to the five key objectives. This is followed by the theories postulated from the findings and recommendations for future studies. It noted how OSC has evolved over time, the limitations of traditional construction and the benefits of Offsite Construction. The problem statement borders around why OSC adoption is low despite its potential to help address the UK housing deficit issues the UK government is trying to overcome. It also looked at how OSC can improve the ecosystem by reducing UKCI carbon footprint, thereby, contributing to environmental sustainability in the UK Net-Zero ambition. It highlighted the objectives through which the aim was achieved.

Objective 1:

To conduct systematic literature review (SLR) in identifying and synthesising commonly reported OSC adoption influencing factors across international contexts, including granular (un)popular ones.

The study reported on the systematic literature reviews conducted to identify the drivers and barriers of OSC from a global perspective. It highlighted and discussed commonly reported drivers and barriers and noted the most reported influencing factors identified by counts (*See sections 2.3.2 and 2.3.3, Appendix 1 and 2*). The SLR noted that there is lopsided understanding in how the drivers and barriers influencing OSC adoption has been reported over time, and this may be part of what is responsible for OSC low adoption. It spotted probable ‘causal’ issues as what should be measured and tackled while broader factors may discuss the

outcomes. This, as observed, would improve the reporting of factors and improve the understanding of how the causal issues inter-play within the broader factors.

Objective 2:

To evaluate and establish, from the globally identified OSC adoption influencing factors, the relevant and applicable ones to the UK context through qualitative interviews with UKCI professionals.

The interview findings showed, like the finding the SLR, that the current sets of factors being examined as influencing OSC adoption have constituent elements (issues). Issues such as procurement methods, construction speed, timesaving, historical perception, cultural views, cost perception, delivery and quality control, low waste generation, and improved health and safety emerged as some of the most mentioned issues with strong influences on wider OSC adoption in the UK ***See section 5.5.1 and Appendix 7***. The themes that emanated from the content analysis as having strong influence on wider OSC adoption in the UK were Supply Chain Logistics, Timesaving, productivity and perception (attitude). This further reinforces the call for root-cause analysis of the broadly reported factors influencing OSC adoption in the UK and globally.

Objectives 3 and 4:

To triangulate findings from the interview analysis with a UK-focused SLR in designing a UK context-specific survey instrument for quantitative data collection.

To identify and establish the most critical factors influencing OSC adoption in the UK through quantitative analysis and feature selection (FS) techniques using ten (10) commonly identified FS algorithms/models.

The study validated the interview outcomes and thereafter triangulated the interview findings with SLR 3 outcomes to develop a survey questionnaire. The questionnaire was used to gather quantitative OSC project data in establishing the very critical OSC influencing factors within the UKCI. The questionnaire developed measured the granular issues observed under the broader commonly reported factors, which were terms constructs in the questionnaire.

The quantitative analysis and feature selection (FS) exercise using ten (10) FS models identified eight features from five constructs as most critical to OSC adoption in the UK within the limits of the data used and the experiments performed. *See section 7.2.2*

This study observed that most of the factors strongly influencing OSC adoption globally are similar to those influencing OSC adoption in the UK. According to the indicators used to develop hypothesis (SLRs and the interview analysis findings), and the factors deduced from FS (using MCC and BC), only OSC Building whole life cycle, Monotonous perception, Ratio of site size to buildable area issues that appeared as critical factors but showed no strong significance from feature extracted during hypothesis testing. *See section 9.1.3.*

Objective 5:

To develop a ML predictive model with the identified critical factors using ten (10) commonly identified ML algorithms and determine the best-performing predictive model for OSC adoption in the UK.

In a fast changing and developing world, driven by meteoric advancements in artificial intelligence (AI), the study understands that the issues and factors influencing OSC are not static. The study identified building a system that aggregate recent and on-going OSC project

data repository for the model developed is critical to understanding the varying trends in OSC usage and applying AI for future prediction. The study, from the project data gathered, developed seven hundred and twenty (720) predictive models for OSC adoption in the UK from the various ML experiments (MCC and BC using 80:20 and 70:15:15 splitting ratios iterated through nine (9) random states). It identified logistics regression at random state 42 as the best and most generalisable and interpretable wider OSC adoption model in the UK within the context of this study. This model, can in the immediate, support wider OSC pursuit target in the UK. However, as ML advances and better models evolves, the process described in this research and the data aggregation framework proposed can become the basics or base for recalibrating OSC adoption prediction possibilities.

With the most critical factors influencing OSC adoption in the UK established through rigorous FS method in this study, and a generalisable OSC adoption predictive model developed, the study achieved its aim.

This study therefore concludes that for OSC adoption to gain the desired momentum in the UK, planning authorities officials need to be updated on OSC knowledge and developments. Also, the RIBA-PoW stages informing approval checklist needs to be updated to reflect disruption brought about by OSC design and construction process. (*See section 9.2.1 discussions*). Also, to improve OSC adoption, more construction consortium need to update on DfMA design technicality and capacity. They should also communicate same to clients in clear terms. The numerous advantages of OSC such as scalability, leading to timesaving and consequently cost saving and improved on-site safety have to become the strong marketing elements of OSC to recreate awareness on OSC and potential increased adoption.

The study also concludes that there cannot be the development of good prediction for the future of OSC without a mechanism for gathering actual OSC project data. The stakeholders, especially government and OSC champion should concert efforts and gather OSC project data to help design data-informed policies for widening OSC adoption. To strengthen the conclusions reached, this study postulates the following theories for the wider adoption of OSC in the UK. The theories simultaneously provide some recommendations from the study.

Study Contributions

A. Scholarly and Conceptual Contributions

This thesis advances the Offsite Construction (OSC) adoption discourse by reframing adoption not as a single-dimension technical or economic problem, but as a multi-layered socio-technical transition process requiring simultaneous consideration of behavioural, organisational, infrastructural, and data-driven decision dimensions. While previous OSC studies (Ajayi et al. 2019; Blismas and Wakefield 2009; Pan, Gibb, and Dainty 2007; Rahman 2014) have predominantly focused on high-level drivers and barriers, this research demonstrates that such aggregation obscures the underlying granular mechanisms through which adoption resistance or acceptance actually occurs. By systematically decomposing macro adoption constructs into measurable sub-factors, the study establishes a more precise analytical basis for understanding OSC uptake dynamics in the United Kingdom construction industry.

A second major scholarly contribution lies in the theoretical repositioning of OSC adoption through change-management-centred interpretation. Most reports on OSC adoption have not paid much attention to the transition challenges and impact from traditional construction to OSC. Thus, the integration of ADKAR and CBAM, together the UK's major construction institutional framework, RIBA-PoW, as theoretical underpinnings move OSC adoption

research beyond descriptive categorisation toward structured behavioural and institutional transition modelling. More significantly, the study extends the traditional linear ADKAR model into a cyclic $ADKAR \rightleftharpoons A$ type feedback-responsive structure, demonstrating how repeated awareness reinforcement through real project showcasing can sustain long-term adoption momentum, a dimension largely absent from existing OSC adoption theory applications. See **Figure 10.1** for the extended ADKAR framework with some OSC-focused action points for wider OSC adoption possibilities.

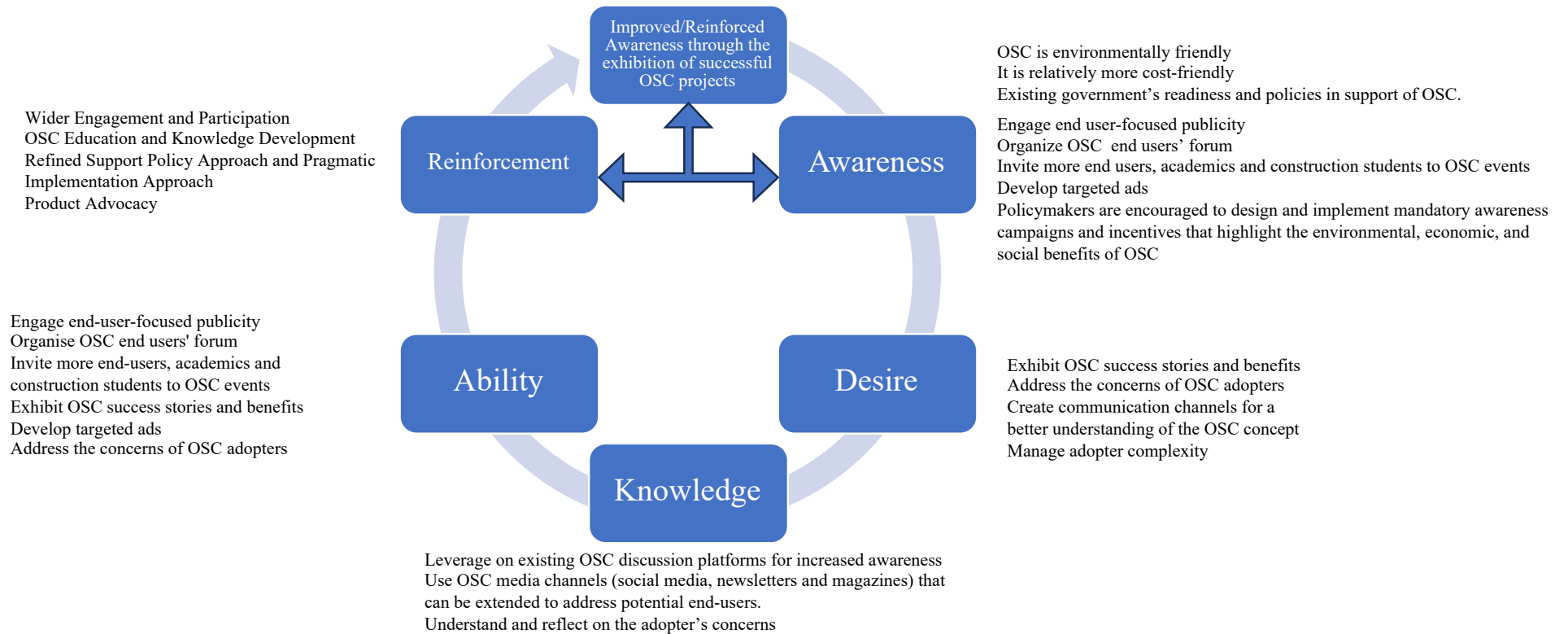


Figure 10.1: Extended ADKAR Model

Third, the research contributes to theory development by proposing early-stage mid-range theory scaffolding for OSC adoption, arguing that adoption must be examined through process frameworks such as RIBA Plan of Work-aligned transition mapping. This offers a pathway for future research to evolve OSC adoption knowledge from descriptive empirical observation toward cumulative theoretical abstraction, addressing the long-standing theory deficit identified across OSC literature.

B. Methodological Contributions

Methodologically, this thesis delivers one of the most comprehensive empirical pipelines currently applied to OSC adoption research. The pluralistic approach study uniquely integrates: Global SLR → Theoretical & analytical methods SLR → UK-focused SLR → Qualitative industry interviews → Triangulated instrument development → Quantitative survey → Multi-Method feature selection → Comparative machine learning predictive modelling

This structured evidence translation pipeline demonstrates how qualitative industry knowledge can be operationalised into structured datasets suitable for predictive analytics, a methodological gap already acknowledged in some OSC reports (Oti-Sarpong et al., 2021; Payne & Serin, 2023; Saad, et al., 2023a, 2023c) but yet to be executed in any OSC research. The application of multiple feature selection methods prior to model development further strengthens methodological robustness by reducing feature bias risk and improving predictive reliability. This approach moves OSC adoption modelling beyond single-method statistical inference toward evidence-weighted predictive modelling, enabling probabilistic forecasting of adoption likelihood rather than retrospective explanation alone. This is to say, by integrating triangulated qualitative evidence, statistical validation, and multi-method feature selection, the study ensures that predictive models are informed by empirically and theoretically robust variables rather than purely statistical optimisation.

Additionally, the study demonstrates the viability of using proxy-indicator datasets (derived from structured perception-project reporting) in environments where national project-level OSC data repositories are absent — a major constraint currently limiting data-driven OSC policy evaluation in the UK.

C. Empirical Contributions to OSC Knowledge

Empirically, this research provides one of the most comprehensive UK-context OSC adoption evidence bases by integrating professional lived-experience insight with statistically validated factor criticality ranking and predictive modelling. The study confirms that OSC adoption is not governed by isolated dominant factors but by interdependent adoption ecosystems, where logistics infrastructure, design processes, supply chain readiness, behavioural perception, and organisational capability interact dynamically.

The identification of logistics-linked adoption constraints, including module-transportation readiness and accessibility, site logistics capacity, and infrastructure readiness, provides strong empirical grounding for policy and planning reform discourse, extending OSC adoption conversation beyond design and manufacturing efficiency narratives.

Furthermore, the study empirically validates the argument that qualitative perception-driven insights alone are insufficient to establish factor criticality. By quantitatively testing qualitative insights using project-proxy data and feature selection-driven modelling, the research establishes a stronger evidential hierarchy for OSC adoption decision-making.

D. Policy, Industry and Strategic Sector Contributions

Beyond academia, the thesis provides actionable pathways for UK construction modernisation policy. The research challenges the historical over-concentration of OSC adoption initiatives on construction professionals alone and demonstrates the need to reposition OSC as a market-

facing manufactured product, requiring engagement with end-users, developers, planners, financial actors, and supply chain ecosystems simultaneously.

The predictive modelling framework provides early foundations for national OSC decision-support systems capable of supporting investment decisions, supply chain planning, and policy incentive targeting. In a policy environment increasingly concerned with housing supply acceleration, productivity improvement, and Net-Zero delivery, this provides a critical transition from descriptive policy support toward predictive policy intelligence capability.

The study also contributes to the emerging digital construction intelligence agenda by demonstrating how machine learning can support sector transition strategy, not just project optimisation. By positioning predictive modelling as a policy and strategy-support tool, the research aligns OSC adoption research with broader UK digital built environment transformation agendas.

The proposed OSC data aggregation framework concept further supports long-term development of national construction data ecosystems, which are currently fragmented across project silos. This creates foundational architecture for future real-time adoption monitoring and decision-support platforms.

E. Societal and Sustainability Contributions

At a societal level, this research contributes directly to three national strategic priorities: Housing supply acceleration, Construction productivity transformation and Net-Zero carbon transition. By linking adoption prediction with real-world deployment feasibility indicators, the research supports more efficient allocation of public and private capital toward construction methods most likely to deliver sustainable housing outcomes at scale.

Summing up the study contributions, this thesis moves OSC adoption research from descriptive factor listing toward predictive, theory-informed, multi-method adoption science. It establishes

a replicable evidence pipeline linking global knowledge synthesis, contextual validation, behavioural and institutional theory integration, OSC adoption factor identification and predictive modelling, providing both academic and practical foundations for accelerating OSC adoption in the United Kingdom and comparable advanced construction economies.

10.2 LIMITATIONS

Nevertheless the employed methodological robustness employed, the study recognises some inherent limitations. One such limitation is the dependence on the OSC factors available in existing literature at the time of review (2021, 2024). While the global and UK-focused SLRs were thorough, they were limited to English-language publications between 2000 and 2024, the review protocol and the database searched. This may have excluded other or more recent relevant academic and grey literature or non-English academic work that could offer additional insights. Additionally, the absence of school's subscription to databases like Web of Science and ACSE limited the richness of factors that might have been extracted from their articles.

The interview sample, although drawn from experienced professionals, was limited to twelve participants and may not have reflected the full spectrum of perspectives across more sectors and regions of the UKCI, even though only M & E personnels seem not to have been interviewed. Transferability of insights to the broader industry should therefore be approached with caution (Wusu, Alaka, Oseghale, Yusuf, Sunmola, et al., 2025).

The predictive modelling components were also constrained by lack of access to direct project-level OSC datasets, though the project reported are believed to be real-world projects as advised by the survey questionnaire instructions. Due to the absence of a national OSC project data

repository -an issue highlighted by Wusu et al. (2025) and Ridings (2024), the machine learning models were developed using Likert scale proxy indicators derived from self-reported OSC projects, rather than directly extracted OSC project data with actual project performance metrics. As a result, the findings remain theoretically predictive rather than operationally verified.

While attempting to work with some of the best classifications models possible for feature selection, some of the commonly reported models returned less than twenty-five (25) features for the top features selected from each model. This may have also impacted the critical factors arrived at during feature selection.

Though, the machine learning techniques used in this study are well-established, they are not completely immune to common development shortcomings like overfitting, class imbalance, and interpretability trade-offs even though measure were taken to reduce these types of limitations to the very barest minimum. Some of the measures taken were careful preprocessing, cross-validations, evaluation with metrics like AUC-ROC, and a focus on transparency over algorithmic complexity. While Machine Learning (ML) holds significant promise in predictive construction analytics (Alaka et al., 2019; Tixier et al., 2016), the models developed in this study were not validated in live industry applications, and no real-time decision support tool was deployed. The MCC approach showed limitations in this study while the BC approach exhibited better performance and generalisability for both Accuracy and AUC values. Interestingly, BC demonstrated the best model for this study– the model with the best performance, thus informing most of the conclusions reached in this study. However, model generalisability remains theoretical, and future studies may need to evaluate ML-driven

predictions in real project contexts for practical refinement and validation. Future research are advised to refine and validate these models in live decision-support systems within construction project environments.

Lastly, the strength of reporting in the quantitative phase of this study is limited by the statistics knowledge level of the researcher.

10.3 DIRECTION FOR FUTURE STUDIES

Future OSC adoption research should prioritise development of mid-range adoption transition theories grounded in real industry behavioural evidence rather than relying solely on technology adoption models transferred from other sectors. National demonstrator programmes should also be used intentionally as behavioural reinforcement mechanisms within adoption strategy design.

Future OSC research should adopt integrated qualitative-to-predictive pipelines, particularly where national project datasets are incomplete. Government and industry bodies should prioritise development of standardised OSC project data repositories to enable longitudinal predictive modelling and policy evaluation.

Construction project planning frameworks should incorporate early-stage OSC feasibility logistics assessments. Design procurement pathways should be adjusted to enable earlier supply chain integration and earlier design freeze points for projects intending to adopt OSC.

UK construction modernisation policies should transition from generic MMC encouragement toward targeted OSC adoption readiness frameworks incorporating logistics infrastructure readiness, supply chain maturity indicators, and behavioural readiness measures.

Future national construction digital transformation programmes should incorporate OSC adoption intelligence dashboards integrating project, logistics, performance, and cost datasets into unified decision-support platforms.

OSC adoption should be formally linked to national housing delivery and decarbonisation strategies through measurable adoption targets and monitored through national construction performance dashboards.

Number of words: <85,000. (~83,914)

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PHD PLAN

ROADMAP TO COMPLETING PHD PROGRAMME IN HERTFORDSHIRE BUSINESS SCHOOL

(February 2021- August 2023)

February 2021- September 2021	-	INITIAL REGISTRATION ASSESSMENT
October 2021 – September 2022	-	SECOND YEAR PROGRESSION REPORT
April 2023	-	Develop survey questionnaire/ Pilot Questionnaire Administer Questionnaire/Propose another Paper
May 2023	-	Complete Research Methodology and commence Thesis Analysis
June 2023	-	Complete quantitative analysis
July 2024	-	Reporting analysis of result
August 2024	-	Reviewing result analysis with supervisors
September 2024	-	Drawing up Conclusions and Recommendations Grammarly/Plagiarism Check Completed

References and Bibliography completed

- October 2024 - General Review with Supervisors in readiness for submission
- July 2025 - Submission to PG School/Doctoral College

APPENDICES

APPENDIX 1: Drivers Identified from Literature Review (SLR 1)

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
1	Reduced time/schedule	20	Time	40
2	Speedy delivery <i>(Bendi, Rana, Arif, Goulding and Sawhney, 2020; Orlowski, 2020; Razkenari et al., 2020; Lu et al., 2021; Malla et al., 2021; Saad et al., 2021; Tsz Wai et al., 2021; Zhang, Kang and Zhong, 2021; Zhao et al., 2021)</i>	9	Efficiency	
3	Reduced risk- ability to freeze design on time and avoid alterations to cost and time.	7		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
	<i>(Calvo et al., 2019; Dixon-Ogbechi & Adebayo, 2020; M. Pan & Pan, 2019; W. Pan & Hon, 2020a; Razkenari et al., 2020; I. Y. Wuni & Shen, 2021; Zhao et al., 2021)</i>			
4	Reduced construction time and site works. <i>(Jin, Ekanayake and Shen, 2021; Saad et al., 2021; Zhang, Kang and Zhong, 2021; Zhao et al., 2021)</i>	4		
5	Supply chain efficiency and traceability. <i>(Dixon-Ogbechi & Adebayo, 2020; W. Jiang, Wu, et al., 2020; M. Pan & Pan, 2019; Zhao et al., 2021)</i>	4	Supply Chain Management	4

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
6	Potential to address skill/labour shortages. <i>(Andersson and Lessing, 2020; An et al., 2020; Dixon-Ogbechi and Adebayo, 2020; Luo et al., 2020; Z. Wang et al., 2020; Balogun, Awonuga and Abowen-Dake, 2021; Lu et al., 2021; Saad et al., 2021; Tsz Wai et al., 2021; Y. Liu et al., 2021; Zhao et al., 2021; Wuni and Shen, 2022)</i>	14	Improved Productivity	39
7	Standardized material and processes <i>(Sutrisna et al., 2018; Calvo et al., 2019; Phang, Chen and Tiong, 2019; Saad et al., 2021)</i>	4		
8	High-level consistency <i>(Jin, Ekanayake and Shen, 2021; Saad et al., 2021)</i>	2		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
9	Ability to manoeuvre ways/cranes on (constrained) sites. <i>(I. Y. Wuni et al., 2021b; Zhao et al., 2021)</i>	2		
10	Requires a smaller number of cranes on site. <i>(I. Y. Wuni et al., 2021b)</i>	1		
11	Better tolerances <i>(Zhao et al., 2021)</i>	1		
12	Efficient Output	13		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
	<i>(T. B. Balogun et al., 2021; Daget & Zhang, 2019; Y. Liu et al., 2021; L. Luo et al., 2020; Malla et al., 2021; Mohamed et al., 2020; W. Pan & Hon, 2020a; Sutrisna & Goulding, 2019b; Tai et al., 2021; Tsz Wai et al., 2021; I. Wuni, Shen, Robert, et al., 2020; Yang & Pan, 2020; J. X. Zhou et al., 2021a)</i>			
13	Improved health and safety <i>(Calvo et al., 2019; Conforti et al., 2019; Pan and Pan, 2019; Sutrisna and Goulding, 2019; An et al., 2020; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Gbadamosi et al., 2020; Pan and Hon, 2020; Razkenari et al., 2020; Wuni et al., 2020; Yang and Pan, 2020; Z. Wang et al., 2020; Jin, Ekanayake and Shen, 2021; Lin et al., 2021; Lu et al., 2021; Saad et al., 2021; Tai et al., 2021; Tsz Wai et al., 2021; Zhao et al., 2021; Zhou et al., 2021; Wuni and Shen, 2022)</i>	21	Safety and Wellbeing	27

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
14	Safer working conditions/environment <i>(Goh and Goh, 2019; Wang and Pan, 2020; Wuni et al., 2020; Z. Wang et al., 2020; Saad et al., 2021)</i>	5		
15	Stable/Secured job <i>(Saad et al., 2021)</i>	1		
16	Waste reduction. <i>(Ahmad, Soetanto and Goodier, 2019; Calvo et al., 2019; Phang, Chen and Tiong, 2019; Andersson and Lessing, 2020; An et al., 2020; Bendi, Rana, Arif, Goulding and Sawhney, 2020;</i>	19	Environment and Sustainability	61

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
	<i>Ismail, 2020; Orlowski, 2020; Wang and Pan, 2020; Z. Wang et al., 2020; H. Liu et al., 2021; Rajanayagam et al., 2021; Saad et al., 2021; Tsz Wai et al., 2021; Wuni and Shen, 2021, 2022; Y. Liu et al., 2021; Zhao et al., 2021; Zhou et al., 2021)</i>			
17	Better environmental performance <i>(Sutrisna et al., 2018; Wuni, Shen and Mahmud, 2019; Yang, Pan and Pan, 2019; Andersson and Lessing, 2020; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Dixon-Ogbechi and Adebayo, 2020; Ismail, 2020; Wang and Pan, 2020; Yang and Pan, 2020; Ginigaddara et al., 2021; Jin, Ekanayake and Shen, 2021; Lu et al., 2021; Malla et al., 2021; Saad et al., 2021; Tai et al., 2021; Wuni and Shen, 2021, 2022; Zhao et al., 2021)</i>	18		
18	Sustainability	10		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
	<i>(Calvo et al., 2019; Phang, Chen and Tiong, 2019; Orlowski, 2020; Razkenari et al., 2020; Balogun, Awonuga and Abowen-Dake, 2021; H. Liu et al., 2021; Jin, Ekanayake and Shen, 2021; Tsz Wai et al., 2021; Zhao et al., 2021; Wuni and Shen, 2022)</i>			
19	Lower carbon emission <i>(An et al., 2020; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Yang and Pan, 2020; Z. Wang et al., 2020; H. Liu et al., 2021)</i>	5		
20	Energy efficiency <i>(H. Liu et al., 2021; Malla et al., 2021; I. Y. Wuni et al., 2019; Yang et al., 2019; Yang & Pan, 2020)</i>	5		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
21	Less environmental and social disruption <i>(Tai et al., 2021; Yang & Pan, 2020)</i>	2		
22	Cleaner site <i>(Bendi, Rana, Arif, Goulding and Sawhney, 2020)</i>	1		
23	Deconstructability <i>(Z. Wang, Wang, Hu, et al., 2020)</i>	1		
24	Improved delivery process	14		14

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
25	Improved efficiency/Communication <i>(Abey and Anand, 2019; Goh and Goh, 2019; Zhang et al., 2019; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Dixon-Ogbechi and Adebayo, 2020; Pan and Hon, 2020; Balogun, Awonuga and Abowen-Dake, 2021; Lin et al., 2021; Zhao et al., 2021; Zhou et al., 2021; Wuni and Shen, 2022)</i>	11	Business Management and Efficiency	36
26	Improved construction process, integrity, and supply management <i>(Abey & Anand, 2019; Gbadamosi et al., 2020; X. Jin et al., 2021; T. Lin et al., 2021; H. Liu et al., 2021; W. Pan & Hon, 2020a; Z. Wang & Pan, 2020; I. Y. Wuni & Shen, 2021)</i>	8		
27	Project predictability	4		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
	<i>(Abey & Anand, 2019; Sutrisna, Cooper-Cooke, et al., 2018b; Zhao et al., 2021; J. X. Zhou et al., 2021a)</i>			
28	Better team management <i>(Saad et al., 2021)</i>	1		
29	Quick adjustment to technology disruptions <i>(T. Lin et al., 2021; W. Pan & Hon, 2020a; Z. Wang, Wang, Hu, et al., 2020; Yang et al., 2018; Yang & Pan, 2020)</i>	5		
30	Enhanced collaboration	4		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
	<i>(Ahmad, Soetanto and Goodier, 2019; Zhang et al., 2019; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Wuni, Shen and Robert, 2020)</i>			
31	Opportunity to improve business and product outcomes. <i>(Zhao et al., 2021)</i>	1		
32	Modular scalability <i>(Zhao et al., 2021)</i>	1		
33	Minimal disruption to business models <i>(Bendi, Rana, Arif, Goulding and Sawhney, 2020)</i>	1		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
34	Government intervention programmes (incentives and policies) <i>(Calvo et al., 2019; Gbadamosi et al., 2020; Z.-A. Ismail, 2020; W. Jiang, Wu, et al., 2020; T. Lin et al., 2021; Y. Liu et al., 2021; Malla et al., 2021; W. Pan & Hon, 2020a; W. Zhang et al., 2021)</i>	9	Regulatory Policies	9
35	Improved quality <i>(Sutrisna et al., 2018; Ahmad, Soetanto and Goodier, 2019; Calvo et al., 2019; Phang, Chen and Tiong, 2019; Sutrisna and Goulding, 2019; Yang, Pan and Pan, 2019; Andersson and Lessing, 2020; An et al., 2020; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Dixon-Ogbechi and Adebayo, 2020; Ismail, 2020; Jiang, Wu and Cao, 2020; Luo et al., 2020; Orłowski, 2020; Pan and Hon, 2020; Razkenari et al., 2020; Ginigaddara et al., 2021; Jin, Ekanayake and Shen,</i>	25	Quality Management	33

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
	<i>2021; Lin et al., 2021; Lu et al., 2021; Rajanayagam et al., 2021; Saad et al., 2021; Y. Liu et al., 2021; Zhao et al., 2021; Wuni and Shen, 2022)</i>			
36	Improved whole life cycle. <i>(Abey & Anand, 2019; L. Luo et al., 2020; Orlowski, 2020; W. Pan & Hon, 2020a; Phang et al., 2019; Razkenari et al., 2020; Sutrisna, Cooper-Cooke, et al., 2018b; Z. Wang, Wang, Hu, et al., 2020)</i>	8		
37	Cost-effectiveness <i>(Bendi, Rana, Arif, Goulding and Sawhney, 2020; Gbadamosi et al., 2020; Lu et al., 2021; Tai et al., 2021; Zhang, Kang and Zhong, 2021; Zhao et al., 2021)</i>	6	Cost Advantage	15

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
38	Reduced cost <i>(Ahmad, Soetanto and Goodier, 2019; Ginigaddara et al., 2021; Jin, Ekanayake and Shen, 2021; Saad et al., 2021)</i>	4		
39	Quick/Better ROI <i>(Sutrisna et al., 2018; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Dixon-Ogbechi and Adebayo, 2020; Razkenari et al., 2020)</i>	4		
40	Ability to avert inflation. <i>(Zhao et al., 2021)</i>	1		

S/No	Findings (Factors)	Factor Count	Sub-Theme	Sub-Theme Count
		276		276

APPENDIX 2: Barriers identified from Literature Review (SLR 1)

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
1	Negative/historical perceptions relating to premanufactured/offsite products. <i>(Abey & Anand, 2019; Ahmad et al., 2019b; X. Jin et al., 2021; T. Lin et al., 2021; Lu, Lee, et al., 2021; S. Saad et al., 2021a; Zhao et al., 2021)</i>	7	User's Perception of OSC	19
2	Clients' requirements, resistance, and scepticism. <i>(Lu, Lee, et al., 2021; M. Pan & Pan, 2019; Yang et al., 2018)</i>	3		
3	Customer/end users' satisfaction	3		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Ahmad et al., 2019b; I. Y. Wuni & Shen, 2022; Zhao et al., 2021)</i>			
5	Product recall and its associated cost /cost /project uncertainty. <i>(An et al., 2020; Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; L. Luo et al., 2020)</i>	3		
6	Concerns with the quality of OSC products. <i>(Z. Zhang et al., 2021b; Zhao et al., 2021)</i>	2		
7	Customer satisfaction <i>(J. K. Ofori-Kuragu & Osei-Kyei, 2021)</i>	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
8	Digital tech skill/fabrication knowledge shortage. <i>(W. Jiang, Wu, et al., 2020; Y. Liu et al., 2021; Phang et al., 2019; Razkenari et al., 2020; I. Y. Wuni & Shen, 2022)</i>	5	Technologic al Disruption	19
9	Technology/ICT disruption. <i>(Ahmad et al., 2019b; He et al., 2020; W. Jiang, Wu, et al., 2020; Yang et al., 2018; Z. Zhang et al., 2021b)</i>	5		
10	Absence of dedicated OSC innovations. <i>(Abey & Anand, 2019; He et al., 2020; Orłowski, 2020)</i>	3		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
11	Socio-technical relationship between/among Innovative Building Technologies (IBTs) during evolution. <i>(He et al., 2020; I. Y. Wuni & Shen, 2022)</i>	2		
12	Complex interfacing between systems/construction process. <i>(Luo et al., 2020; Pan and Hon, 2020; Saad et al., 2021)</i>	3		
13	Non-adherence to specified/strategic technological approach. <i>(W. Pan & Hon, 2020a)</i>	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
14	Lack of a credible business case/model for the use of offsite. <i>(Ahmad et al., 2019b; Ginigaddara et al., 2021b; X. Jin et al., 2021; Lu, Lee, et al., 2021; J. K. Ofori-Kuragu & Osei-Kyei, 2021; W. Pan & Hon, 2020a)</i>	6	Supportive Business Model	9
15	Lack of resources to adequately transit to satisfy market demands. <i>(Ginigaddara et al., 2021b; Lu, Lee, et al., 2021)</i>	2		
16	Lack of comprehensive business case/model for the use of offsite and pre-manufactured solutions. <i>(J. K. Ofori-Kuragu & Osei-Kyei, 2021)</i>	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
17	Performance of structures under seismic effects. <i>(Abdelmageed et al., 2020; Conforti et al., 2019; M. Pan & Pan, 2019; I. Wuni, Shen, Robert, et al., 2020; I. Y. Wuni & Shen, 2022, 2021; Yang et al., 2019; Z. Zhang et al., 2021b)</i>	8	Structural Performanc e	23
18	Knowledge of assembly/installation techniques. <i>(Abey & Anand, 2019; Razkenari et al., 2020; Z. Wang & Pan, 2020; I. Y. Wuni & Shen, 2022; Yang et al., 2019; J. X. Zhou et al., 2021a)</i>	6		
19	Connection issues.	4		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Rajanayagam et al., 2021; I. Wuni, Shen, Robert, et al., 2020; I. Y. Wuni et al., 2019; I. Y. Wuni & Shen, 2021)</i>			
20	Load supporting capability of structures. <i>(T. Lin et al., 2021; S. Saad et al., 2021a; I. Y. Wuni & Shen, 2021; Z. Zhang et al., 2021b)</i>	4		
21	Positioning of modules issues. <i>(Rajanayagam et al., 2021)</i>	1		
22	Transportation.	12		82

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Abey & Anand, 2019; An et al., 2020; Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; Daget & Zhang, 2019; X. Jin et al., 2021; Lu, Lee, et al., 2021; J. K. Ofori-Kuragu & Osei-Kyei, 2021; Razkenari et al., 2020; I. Y. Wuni & Shen, 2022; Yang et al., 2019; J. X. Zhou et al., 2021a)</i>		Site logistics and supply chain managemen t	
23	Delays/planning in production, material procurement/time and schedule. <i>(Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; Ginigaddara et al., 2021b; Z.-A. Ismail, 2020; W. Jiang, Wu, et al., 2020; L. Luo et al., 2020; W. Pan & Hon, 2020a; Sutrisna & Goulding, 2019b; Z. Wang, Wang, Hu, et al., 2020; Z. Wang & Pan, 2020; I. Y. Wuni et al., 2019; Yang et al., 2019)</i>	11		
24	Coordination/management capability of supply chain.	8		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Ahmad et al., 2019b; Daget & Zhang, 2019; Z.-A. Ismail, 2020; X. Jin et al., 2021; L. Luo et al., 2020; Sutrisna, Cooper-Cooke, et al., 2018b; Z. Wang, Wang, Hu, et al., 2020; Z. Wang & Pan, 2020)</i>			
25	Logistics and operations. <i>(Daget & Zhang, 2019; X. Jin et al., 2021; T. Lin et al., 2021; Lu, Lee, et al., 2021; J. K. Ofori-Kuragu & Osei-Kyei, 2021; W. Pan & Hon, 2020a; J. X. Zhou et al., 2021a)</i>	7		
26	Absence of hedging strategy and stocking/storage safety.	6		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Abey and Anand, 2019; Daget and Zhang, 2019; Bendi, Rana, Arif, Goulding and Sawhney, 2020b; Jin, Ekanayake and Shen, 2021; Wuni, Shen and Antwi-Afari, 2021; Wuni and Shen, 2022)</i>			
27	Availability of local materials/machineries /labour. <i>(An et al., 2020; Lu, Lee, et al., 2021; L. Luo et al., 2020; W. Pan & Hon, 2020a; I. Y. Wuni & Shen, 2022)</i>	5		
28	Unsuitable supply chain process. <i>(Daget and Zhang, 2019; Ginigaddara et al., 2021; Jin, Ekanayake and Shen, 2021; Saad et al., 2021)</i>	4		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
29	Road size and regulations. <i>(X. Jin et al., 2021; L. Luo et al., 2020; I. Y. Wuni & Shen, 2022)</i>	3		
30	Poor site productivity. <i>(Lu, Lee, et al., 2021; Razkenari et al., 2020; Sutrisna & Goulding, 2019b)</i>	3		
31	Manufacturing capability of industries. <i>(Abey & Anand, 2019; Z.-A. Ismail, 2020; Lu, Lee, et al., 2021)</i>	3		
32	Cross border logistics.	3		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; Tsz Wai et al., 2021; Z. Wang & Pan, 2020)</i>			
33	Size, shape, and weight of modules to be lifted. <i>(An et al., 2020; L. Luo et al., 2020; I. Y. Wuni et al., 2021b)</i>	3		
34	Site location/ constrain. <i>(J. K. Ofori-Kuragu & Osei-Kyei, 2021; Sutrisna, Cooper-Cooke, et al., 2018b)</i>	2		
35	Manoeuvring cranes on site. <i>(L. Luo et al., 2020; I. Y. Wuni et al., 2021b)</i>	2		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
36	Complex nature of OSC modules supply. <i>(X. Jin et al., 2021; L. Luo et al., 2020)</i>	2		
37	Small buffer area. <i>(Lu, Lee, et al., 2021)</i>	1		
38	Early involvement of suppliers and contractors <i>(J. X. Zhou et al., 2021a)</i>	1		
39	Managing multiple cranes lifting	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(I. Y. Wuni et al., 2021b)</i>			
40	Wrong delivery <i>(Sutrisna & Goulding, 2019b)</i>	1		
41	Large scale mech equipment required for hoisting. <i>(Jiang, Wu and Cao, 2020; Saad et al., 2021)</i>	2		
42	Lifting and crane work issues. <i>(Phang et al., 2019; Rajanayagam et al., 2021)</i>	2		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
43	Unavailable OSC supporting (local) building codes. <i>(Abey & Anand, 2019; H. Liu et al., 2021; L. Luo et al., 2020; S. Saad et al., 2021a; I. Y. Wuni & Shen, 2021; Z. Zhang et al., 2021b; J. X. Zhou et al., 2021a)</i>	7	Policies, incentives, and Regulations	19
44	Planning regulations <i>(H. Liu et al., 2021; Razkenari et al., 2020; J. X. Zhou et al., 2021a)</i>	3		
45	Government policies <i>(Abey & Anand, 2019; Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; T. Lin et al., 2021; W. Pan & Hon, 2020a; Z. Wang, Wang, Hu, et al., 2020; Yang et al., 2018)</i>	6		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
46	Absence of supporting incentives <i>(Abey & Anand, 2019; X. Jin et al., 2021; Z. Wang, Wang, Hu, et al., 2020)</i>	3		
47	Academic-industry gap <i>(Bendi, Rana, Arif, Goulding and Sawhney, 2020)</i>	1	OSC Knowledge	6
48	Lack of stakeholder's skills (competence) and knowledge <i>(T. B. Balogun et al., 2021; X. Jin et al., 2021; T. Lin et al., 2021; Z. Zhang et al., 2021b)</i>	5		
49	Scarce use of BIM /lean process on OSC.	4		11

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Dixon-Ogbechi and Adebayo, 2020; Pan and Hon, 2020; Razkenari et al., 2020; Saad et al., 2021)</i>		Lack of organization	
50	Level of organizational readiness to transit to OSC. <i>(Abey & Anand, 2019; Bras et al., 2020; Lu, Lee, et al., 2021)</i>	3	readiness to transit to OSC.	
52	Risk-averse nature. <i>(X. Jin et al., 2021; Lu, Lee, et al., 2021; Phang et al., 2019)</i>	3		
53	Dominating traditional method of construction	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(T. Lin et al., 2021)</i>			
54	Initial high capital/escalating construction costs (material, labour) <i>(Abey & Anand, 2019; An et al., 2020; He et al., 2020; H. Liu et al., 2021; Lu, Lee, et al., 2021; J. K. Ofori-Kuragu & Osei-Kyei, 2021; Razkenari et al., 2020; S. Saad et al., 2021a; Sutrisna, Cooper-Cooke, et al., 2018b; Tsz Wai et al., 2021; Z. Wang, Wang, Hu, et al., 2020; I. Y. Wuni et al., 2019; I. Y. Wuni & Shen, 2021)</i>	13	Funding OSC	20
55	Difficulty obtaining mortgage and financing for OSC houses (funding) / expected ROI. <i>(J. K. Ofori-Kuragu & Osei-Kyei, 2021; Yang et al., 2018; Z. Zhang et al., 2021b)</i>	Emerging factor 3		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
56	Complex interfaces between taxes and duties <i>(Lu, Lee, et al., 2021; Tsz Wai et al., 2021)</i>	2		
57	Higher taxes <i>(Lu, Lee, et al., 2021)</i>	1		
58	Achieving economy of scale <i>(Saad et al., 2021)</i>	1		
59	Lack of certification and standardisation systems	5		9

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Ahmad et al., 2019b; T. Lin et al., 2021; Y. Liu et al., 2021; Lu, Lee, et al., 2021; J. K. Ofori-Kuragu & Osei-Kyei, 2021)</i>		Environmen tal	
60	Sustainability issues in relation to the transport of offsite products to the site <i>(J. K. Ofori-Kuragu & Osei-Kyei, 2021; S. Wang & Sinha, 2021b)</i>	2	Sustainabilit y	
61	Energy is high for precast concrete. <i>(S. Wang & Sinha, 2021b)</i>	1		
62	Carbon emission is high for precast concrete.	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(S. Wang & Sinha, 2021b)</i>			
63	Design issues (OSC compliance and compatibility, design freeze, bespoke, monotony, changes. <i>(Abey & Anand, 2019; Ahmad et al., 2019b; An et al., 2020; Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; Calvo et al., 2019; Dixon-Ogbechi & Adebayo, 2020; W. Jiang, Wu, et al., 2020; X. Jin et al., 2021; T. Lin et al., 2021; Lu, Lee, et al., 2021; Phang et al., 2019; Rajanayagam et al., 2021; S. Saad et al., 2021a; Sutrisna & Goulding, 2019b; Z. Wang & Pan, 2020; I. Y. Wuni et al., 2019; J. X. Zhou et al., 2021a)</i>	17	Design Issues	29
64	Long lead time	5		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Abey & Anand, 2019; Ginigaddara et al., 2021b; T. Lin et al., 2021; Lu, Lee, et al., 2021; I. Y. Wuni & Shen, 2021)</i>			
65	Defective designs <i>(Phang, Chen and Tiong, 2019; Bendi, Rana, Arif, Goulding and Sawhney, 2020)</i>	4		
66	Dimensional conflicts/tolerances <i>(An et al., 2020; Bendi, Rana, Arif, Goulding and Sawhney, 2020; Wuni and Shen, 2021)</i>	3		
67	Uncertainty of property market	3		5

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Y. Liu et al., 2021; W. Pan & Hon, 2020a; Phang et al., 2019)</i>		Constructio n Industry Market	
68	Demand and supply forces (economics of real estate int'l market) <i>(Ginigaddara et al., 2021b; W. Pan & Hon, 2020a)</i>	2		
69	Skill/labour shortages <i>(Abey & Anand, 2019; Ahmad et al., 2019b; An et al., 2020; Bras et al., 2020; J. K. Ofori-Kuragu & Osei-Kyei, 2021; S. Saad et al., 2021a; Tai et al., 2021; Tsz Wai et al., 2021; I. Y. Wuni et al., 2021b)</i>	10	Constructio n Industry Managemen t	43
70	Stakeholders divergent views/lack of collaboration/commitment	10		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Abey & Anand, 2019; Ahmad et al., 2019b; An et al., 2020; Bras et al., 2020; L. Luo et al., 2020; W. Pan & Hon, 2020a; Phang et al., 2019; Z. Wang, Wang, Hu, et al., 2020; I. Y. Wuni & Shen, 2022; Yang et al., 2018)</i>			
71	Lack of automatic decision support system <i>(Lu, Lee, et al., 2021)</i>	1		
72	Poor coordination and management of downstream sector <i>(Ginigaddara et al., 2021b; W. Jiang, Wu, et al., 2020; W. Pan & Hon, 2020a; Sutrisna & Goulding, 2019b; Z. Wang & Pan, 2020)</i>	5		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
73	Lack of adequate supervision/management team <i>(An et al., 2020; Lu, Lee, et al., 2021; Tai et al., 2021; Z. Wang, Wang, Hu, et al., 2020)</i>	4		
74	Planning and decision making on use of OSC. <i>(Sutrisna and Goulding, 2019; Pan and Hon, 2020; Lin et al., 2021; Saad et al., 2021)</i>	4		
75	Trade unionism and policies. <i>(X. Jin et al., 2021; L. Luo et al., 2020; I. Y. Wuni & Shen, 2022)</i>	3		
76	Fragmentation of the industry	2		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Bras et al., 2020; Gbadamosi et al., 2020)</i>			
77	Insignificant labour activities <i>(Lu, Lee, et al., 2021)</i>	1		
78	Duplicated work <i>(Lu, Lee, et al., 2021)</i>	1		
79	Lack of experience <i>(Lu, Lee, et al., 2021)</i>	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
80	Tardy reactions facing emergencies. <i>(J. X. Zhou et al., 2021a)</i>	1		
81	Unavailable information/communication exchange platform <i>(Ahmad et al., 2019b; An et al., 2020; Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; Ginigaddara et al., 2021b; T. Lin et al., 2021; Y. Liu et al., 2021; Malla et al., 2021; Phang et al., 2019; Sutrisna, Cooper-Cooke, et al., 2018b; I. Y. Wuni & Shen, 2022; J. X. Zhou et al., 2021a)</i>	11	Communication and Data Management	43
82	Data/information management	7		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Ahmad et al., 2019b; T. B. Balogun et al., 2021; Gbadamosi et al., 2020; Ginigaddara et al., 2021b; Malla et al., 2021; Phang et al., 2019; Z. Zhang et al., 2021b)</i>			
83	Limited OSC research and research funding. <i>(W. Jiang, Wu, et al., 2020; X. Jin et al., 2021; T. Lin et al., 2021; I. Y. Wuni & Shen, 2022)</i>	4		
84	Insufficient data capture on OSC <i>(I. Y. Wuni et al., 2019; Z. Zhang et al., 2021b; J. X. Zhou et al., 2021a)</i>	3		
85	Information gap between designers and manufacturers	3		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Bendi, Rana, Arif, Goulding, & Sawhney, 2020b; L. Luo et al., 2020; I. Y. Wuni et al., 2021b)</i>			
86	Paucity of needed/quality information and data. <i>(Daget & Zhang, 2019; Gbadamosi et al., 2020; Lu, Lee, et al., 2021; L. Luo et al., 2020; Phang et al., 2019; Sutrisna, Cooper-Cooke, et al., 2018b; S. Wang & Sinha, 2021b; I. Y. Wuni et al., 2019)</i>	8		
87	Use of ethnographic data set <i>(J. K. Ofori-Kuragu & Osei-Kyei, 2021; I. Y. Wuni et al., 2019)</i>	2		
88	Lack of information on prefab options and suppliers' alternatives (local supplies)	2		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
	<i>(Saad et al., 2021; Tsz Wai et al., 2021)</i>			
89	Lack of guidance and information <i>(Zhou et al., 2021)</i>	1		
90	Lack of tools to measure adoption level. <i>(Zhou et al., 2021)</i>	1		
91	Loss of schedule information. <i>(Zhou et al., 2021)</i>	1		

S/ No	Barriers Identified	Count	Sub-Theme	Sub-Theme Count
92	Lack of awareness <i>(Ahmad et al., 2019a; Bendi, Rana, Arif, Goulding, & Sawhney, 2020a; J. Goulding et al., 2014; I. Y. Wuni & Shen, 2022)</i>	4	Awareness	4
	Total			343

APPENDIX 3: Detailed Discussion (Drivers and Barriers)

Drivers:

40 OSC distinct driving factors were identified from a list of 276 driving factors mentioned in the relevant literature reviewed (See Table 2.1). 9 aggregating sub-themes emerged from the factors following coding from content analysis. These sub-themes, (Improved productivity, Time-Efficiency, Quality Management, Environment and Sustainability, Safety and Well-being, Improved Construction Business Management, Improved Cost Management, Government interventions, and Supply chain Management) were further coded into themes based on their close relativeness (T. Lin et al., 2021; Newson, 2022). These themes (Operational Optimization, Environmental Sustainability and Safety, Construction Business Management, Cost Advantage, Policy and Interventions, and Supply Chain Logistics) were ranked according to the frequency of their mentions in the reviewed articles and discussed below.

1. ***Improved Productivity:*** This theme is used to aggregate factors relating to production performance. The sub-themes identified as constituting this theme are Improved productivity, Time-Efficiency, Improved delivery process, and Improved quality output.

Transitioning construction projects from an on-site, labour-intensive method into a coordinated and structured factory approach has been reported to add a flavour to productivity and output (Babalola, Ibem and Ezema, 2019). Borrowing a leaf from the manufacturing industry, the construction industry has increased in efficiency and output by employing the lean approach, high-level consistency, better tolerances in measurements, standardized materials and processes and trade specialization. With a frequency count of 41, 40, 39, and 33 observed for Improved productivity, Time-Efficiency, Improved delivery process, Improved quality output,

respectively, Operational Optimization theme ranks the most discussed driving factor in the systematic review conducted.

The review indicated that value-added productive transformation to the fragmented conventional construction method (W. Pan & Hon, 2020a) has increased the construction industry production rate (J. X. Zhou et al., 2021a) through the application of lean practises (Babalola, Ibem and Ezema, 2019; Goh and Goh, 2019, 2019; Omotayo, 2014) time-saving techniques, improved quality output, resulting in enhanced production rate by integrating value-driven production of both prefab 2D and 3D components. The productivity brought about is not limited to project scheduling and factory output only, it extends to supply chain, transportation, delivery and on-site assemblage (Y. Zhai et al., 2017, 2018b). IoT sensors, RFID and tags have been developed to assist the assembly, installation and positioning of the modules or panels rightly and timely. This minimizes probable mistakes that would have resulted in re-works, loss of time, effort and resources (J. X. Zhou et al., 2021a). With automation and large machine applications in carrying out tasks, OSC has equally demonstrated potentials to mitigate the waning construction workforce which is a growing challenge within the industry (Nadim & Goulding, 2009) and improve the industry which had hardly grown above 1% globally over the years.

Unlike the sequential waterfall approach largely used in construction project delivery where a task is usually completed and approved before the next can start (I. Wuni, Shen, Robert, et al., 2020), OSC allows for some form of agile and overlapping sequences that do not have to depend on an end-to-start sequence of work (Azhar et al., 2013). For constructions, designs are frozen early and shop drawings approved quicker, different building or construction segments

and components can be produced concurrently and converged at an agreed state, stage, or time. They are then coupled together to achieve a part of, or the final form to be assembled on site.

A reflection on the state of traditional construction approach and building materials calls for urgent quality improvement. With the rapidly changing climate, there is a need for materials that can shield people from the weather around them to a measurable required standard (Y. Chen et al., 2010). In regions largely exposed to cold like the UK, the quality of materials is required to meet the threshold EPC rating that quite several traditional buildings do not measure up to (Olu-Ajayi et al., 2023). Aside from meeting climatology benchmarks, the buildings are also expected to perform structurally and aesthetically. Another area that calls for quality delivery in the construction sector is quality of workmanship (J. S. Goulding & Rahimian, 2019). All these values and more can be achieved by moving the process into a factory where better quality control and quality assurance measures are applied through close inspection, monitoring, and trials. While the conventional method has invested a great deal of efforts on improving material and component quality in recent years, their efforts are betrayed by the unreason-ability, inefficiency and errors emanating from poor tradesmen workmanship (human interaction) with near-finished state of the project e.g., puncturing a hole in supposed a tight wall or plumbing pipe. These laxities are made up for in the factory-oriented approach of OSC (T. Lin et al., 2021) where most activities are automated and machine-executed to precision. Some of the areas that have experienced massive quality improvement under OSC are insulation properties of materials (Tavares et al., 2021), reduced carbon emission properties of materials (Osmani & O'Reilly, 2009), energy efficiency, moisture and damp resistance of materials (Bras et al., 2020), improved functional and structural connections (Orlowski, 2020),

high consistency, better tolerances, improved whole lifecycle, improved pre-manufactured values (PMV) to mention but a few.

Construction industry work is grossly associated with time-wasting activities and speed constraints bottlenecks resulting in re-works, delays, extended schedules and project completion dates, and increasing requests for extension of time (EOT) (C. N. Egwim et al., 2021). The implications of these are usually budget spike, time loss and return on investment (ROI) loss. Some of these delay-causing activities may be beyond the control of the project team where sometimes it is a force majeure. But the majority of the time-loss-causing activities are traceable to mismanaged human activities (C. Egwim et al., 2022). OSC posits to address this limitation by early design freeze, improved offsite and onsite processes, defined procurement routes and well-managed execution schedules. The approach of OSC has been found to have resulted in saving huge project duration periods as reported from different projects and research work. (X. Li et al., 2017)

Improved Environment and Safety: There is a global call for an improved environment due to the adverse effect climate change is having on the universe (Feldmann et al., 2022). The continual discharge of carbon into the atmosphere is negatively impacting our environment with enormous warming, creating fluctuating weather seasons and health challenges (Babalola, Ibem and Ezema, 2019). The amount of carbon emission released into the environment is traceable to the activities of the construction industry amidst other contributors (S. Wang & Sinha, 2021b). The construction industry is reported to be the second largest industry contributing to global warming (Shi et al., 2017). The acclaimed amount of highly negatively impacting environmental carbon emissions is closely associated with the activities of

traditional construction methods both through its embodied and operational carbon-emitting activities (GBC UK, 2019). The global population rise calls for increased housing supply which implies increased construction and infrastructure activities on the depleted environment (Alonso-Zandari & Hashemi, 2017). A probable way to reduce the carbon emission escalating activities is to move the enormous carbon-emitting construction activities into the factory, thereby, improvising alternative and less carbon emitting material and process (CITB, 2021) that aids quick housing delivery.

OSC has been advocated to be more environmentally friendly than traditional methods of construction (Jayawardana et al., 2023). Improved health and safety, waste reduction, better environmental performance and sustainability were the most frequent factors observed under Environmental Sustainability and Safety. The articles admit that OSC method reduces construction waste significantly (Lu, Lee, et al., 2021). Construction waste accounts for some of the largest industry waste in the world (more than 40%). The majority of this waste, rather than being recycled or re-used, ends up in the landfill (Osmani, 2012). OSC provides room for re-use, recycling and reduction of waste generated rather than discarding such waste in ways that further degenerate the environment (Babalola, Ibem and Ezema, 2019).

OSC has also been found to promote sustainability which is at fore front of global meetings and agendas. Aside from waste reduction, OSC has been found to lower carbon emissions, improve energy efficiency, and encourage deconstructability rather than demolition which creates a great nuisance to the environment (H. Balogun et al., 2022). Moving construction activities away from the site has reduced disruption to site neighbours (I. Wuni, Shen, Robert, et al., 2020), keeps sites cleaner (I. Y. Wuni & Shen, 2021), and reduces onsite incidents and

accidents which have reached all-time high records of death, physical injuries, and emotional trauma to those affected by it and their families (Poh et al., 2018).

The use of improved building materials has also been noted to improve the living conditions of people using OSC buildings through less energy consumption, and less health-threatening issues like little or no mould growths, damp issues, leakages, or vegetative growth associated with exterior building edges. The materials also ensure low conduction of winter cold into buildings thus keeping users relatively warmer than conventional buildings. Working from a factory adds a degree of job stability and security to a construction worker who would have had to jump from one job site to the other.

Construction Business and Cost Management: Major phases of traditional construction business are regimented around the finish-to-start task approach because the next phase is dependent upon the completion of the previous phase (I. Y. Wuni & Shen, 2021). The industry is equally very fragmented and requires a large pool of interdependent skills which often do not collaborate effectively (W. Pan & Hon, 2020a). The consequence of this results in relatively poor management of human and capital resources, slowing down the business activities that could have generated better revenue within a short period (Boothman et al., 2014; Ngoc Nguyen et al., 2020). This business approach also makes engaging technological innovation difficult due to resistance from workers (Andersson & Lessing, 2020b; Lessing & Brege, 2015). The adoption of OSC is poised to quickly adjust to accommodating technological advancement and disruption revolutionizing many industries globally, giving room for modular scalability, enhancing collaboration, mitigating inclement weather, and producing better processes and products. This positive potential of OSC would enhance economic and

construction industry growth, create opportunities to improve business and project outcomes and cause minimal negative disruption to construction business.

Rising cost has been identified as one of the major causes of delay, dispute, and litigation within the construction industry business (W. Pan & Sidwell, 2011; X. Zhai et al., 2014). Effective cost management in construction has been reported as one of the reasons for construction industry's insolvency (H. A. Alaka et al., 2017). Construction industry projects are largely associated with huge project financial losses annually. With the construction sector acclaimed to be about the most contributing sector to the GDP of countries, insolvency of construction companies implies loss of jobs and economic downturns (H. Alaka, Oyedele, Owolabi, Oyedele, et al., 2017). The implications do not end with the construction industries and workers only but extend to the homes and the larger populace. With OSC being characterized by a defined work scope, early design freeze, early and defined procurement, engagement of relevant stakeholders, and reduced project period, a better cost-effectiveness and management structure that would reduce cost is introduced into the project scheme. A quicker and better return on investments (ROI) is therefore promised, if not assured, through reduced customary wastage and inflation aversion.

Government Interventions: with advocacy for a greener environment on the rise globally, many world leaders are lending their voices to the adoption of less carbon-emitting activities in the construction sector. For instance, policies are geared to encourage contractors to embrace OSC and incentives are equally provided to actualize the policies. To enhance the OSC promoting policies, a more user-adopting measures is required to bring effectiveness and impact to these policies.

Supply Chain and Site management: Supply chain and logistics management is one of the most critical segments of construction projects (I. Y. Wuni & Shen, 2020c; W. Zhang et al., 2021). Traditional constructions suffer huge setbacks from supply and logistics failure. Due to tons of different kind of materials needed on-site at different stages of the project, delays, mismatch, damage, and losses has been grossly reported on project sites (Daget & Zhang, 2019). Some of the benefits OSC adds to the supply chain segment of construction projects are robust and well-established supply chain systems. With minimal type of material and component supply, easy traceability of components through the use of advanced traceability technologies like chips, RFIDs, geotags is achieved (Chao et al., 2007b; M. Wang, Wang, Sepasgozar, et al., 2020). OSC can manoeuvre cranes on constrained sites owing to reduced site activities. Also, OSC requires a small number of cranes and crane types on-site, thereby reducing conflict-inducing activities (Z. Zhang et al., 2021b).

Among the 40 distinct drivers collated from 276 mentions of OSC drivers from the literatures, the most mentioned single drivers are improved productivity, health, and safety and... The emerging influencing issues as observed from the review are construction business and cost management which have the potential to positively influence the adoption process of OSC. Some new but salient factors that may further positively influence the adoption of OSC in the near future if critically appraised are job stability and workers' well-being, better team management, modular scalability of projects and inflation aversion.

Barriers:

The emergence and adoption of OSC are faced with several inhibiting factors which scholars have termed barriers (Arif et al., 2017b; Schoenborn, 2012) or risks (Sutrisna & Goulding, 2019b; Wu et al., 2019; I. Y. Wuni et al., 2019). OSC barriers have been reported in various forms, types, and categories by extant literature. This study adds credence to the existing body of knowledge on issues inhibiting the wider adoption of OSC by identifying the nuggets that constitute the building blocks of earlier scholarly identified barriers through a systematic literature review of their works. This study identified 80 distinct barriers from 339 barriers collated in this SLR. The barriers identified were categorized into 15 sub-themes before being aggregated into 8 themes. Not all the sub-themes could be aggregated. Because of the distinctness of some themes, they stood alone, either with a large or low number of factors. Some of the most frequently occurring themes constituting major barriers to the wider adoption of OSC are supply chain management, design and construction technology, construction industry management and OSC knowledge and communication with 82, 72, 57 and 48 mentions respectively. Other barrier themes are attitude, funding, policies and interventions and environmental sustainability.

Supply Chain Management: Projects are defined as temporary endeavours with a start and finish date. The effective management of a project is critical to its success (Wacker, 1998). Supply chain management is a critical path in the build-up to effective project management amidst other factors like cost, scope, time, resources (Guribie et al., 2022; Mao et al., 2018b). From the selection of procurement route, and acquiring material, to transportation and logistics, delivery, stock taking and hedging, supply chain management determines the timely delivery or failure of the project (Y. Zhai et al., 2019b). Supply chain management is not just a challenge in traditional construction, it is a serious challenge in OSC as well considering that OSC is an

emerging construction approach (Z. Wang et al., 2019; W. Zhang et al., 2021). Notable among the factors that constitute supply chain challenges to OSC are transportation, production planning and material procurement, the capability of the supplying company, logistics and operation with 12, 11, 8 and 7 mentions respectively. Other challenges associated with supply chain management as identified from the pieces of literature are hedging strategies, road size regulations, shape and size of the site, access to the site, size, and shape of modules, and managing cranes and other heavy types of machinery on site.

There are different transportation laws guiding different countries and these laws dictate the sizes of roads and the nature of transportation activities allowed on such roads (Tsz Wai et al., 2021). For instance, activities allowed or encouraged on trunk A roads are not the same as those allowed on access roads. This invariably determines what vehicle sizes are also allowed to ply some routes. Where a site designed for OSC is not directly linked from a reasonably sized road, delivering OSC modules which are associated with reasonably large sizes becomes a challenge (Yang & Pan, 2020; Y. Zhai et al., 2019b). Hoisting and managing lifting cranes on such kind of site would also be a challenge (Z. Zhang et al., 2021b). Suffice to summarize it that the nature, size, and location of a site greatly influence the adoption of OSC for such a site. Other issues bothering around supply chain management are cross-border logistics (for products not locally manufactured), wrong delivery and availability of local supply (both labour and material).

Design and Construction Technology: Scholarly works described OSC as both disruptive innovation and a revolutionary approach to construction (Tsz Wai et al., 2021; I. Yahaya. Wuni & Shen, 2019). This implies that OSC does not entirely follow the existing construction

paradigms in many ways. For instance, the design of OSC modules requires another approach different from the conventional construction drawings (Laovisutthichai & Lu, 2021). The new approach is termed Design for Manufacture and Assembly (DfMA), mimicking the manufacturing sector production design approach. A major issue arising from this is that the majority of architects are not versatile in the DfMA approach, thereby inhibiting the wider uptake of OSC (Bao et al., 2021). This cascades into other design issues such as defective OSC designs, dimensional conflicts, tolerance issues, long lead time, changes, creativity-lacking designs, compliance failure (N. Blismas & Wakefield, 2009; Jaillon & Poon, 2010; Shang et al., 2020; Sutrisna & Goulding, 2019b).

Prefabricated building has been reported to perform less than anticipated under seismic effect such as earth tremor or earthquake (Savoia et al., 2017; Xiao et al., 2015). In areas highly or lightly susceptible to earth movements, prefabrication has been reported to give way through connection points and joints (Malla et al., 2021). Therefore, an adequate joining system must be made safe and stable under seismic effects and loads. The load-supporting ability of prefabricated elements has also been queried by extant studies due to the numerous connections required to fit the whole (Badir et al., 2002). Researchers attribute this weakness in OSC to inadequate knowledge of assembly and installation techniques required for OSC (Gan, Chang, Zuo, et al., 2018; Hosseini et al., 2018a).

Technology is fast evolving with many improvements to its dynamics and metrics. The industry at large seems not ready for the technological advancement characterizing the adoption of OSC (Qi et al., 2021; M. Wang, Wang, Sepasgozar, et al., 2020). With a large number of construction workers accustomed to the rigid sequential manner of construction, OSC

experiences some level of resistance (conservatism and protectionism), arising from fears of the unknown, ranging from fear of job loss to fear of upskilling or re-skilling (T. B. Balogun et al., 2021; Razkenari et al., 2020). These are some constituent issues noted to be contributing to resistance OSC adoption factor.

Construction Industry Management: The construction industry is highly fragmented and heavily regimented (Z. Wang, Wang, Hu, et al., 2020; I. Y. Wuni et al., 2019). The existing model guiding its activities is highly premised on a task being completed before the next stage can begin. The market structure is dominated by scarce supply to ensure high demand in keeping the houses price values high (Lye, 2020; Rahimian et al., 2017). In a system where the global population has been on a continual exponential rise, housing shortages will likely remain all-time high with present construction industry management model (Bendi, 2020b; Onososen, 2019). The need to sequence an overlapping approach to close the linear sequence of the regimented industry, revise the dominating traditional model and tone down the short supply market system that keep house prices up has reached an unprecedented imperative (Martinez et al., 2008; Babalola, Ibem and Ezema, 2019; Goulding and Rahimian, 2019). This review study report construction industry business as the second most frequent mention of the barriers inhibiting the wider adoption of OSC with 57 counts. The review observed management industry management, lack of a supportive business model and the construction industry market with 43, 9 and 5 counts respectively as the constituents of this inhibiting theme.

The construction industry is laden with many different stakeholders who hold divergent views on how projects should be executed (Tsz Wai et al., 2021; I. Wuni, Shen, & Robert, 2020). For

instance, the architects hold the overall look (aesthetics) of their structure in high esteem and oftentimes do not want to trade that off for the structural functionality of the building nor the functionality of space areas, thus leading to the emergence and arguments of theories like form follow function and vice-versa (Goncher, Johri and Sharma, 2010; Laovisutthichai and Lu, 2021). Mechanical engineers have been found often at loggerheads with the columns and beams of the structural engineers due to the inability of passage of pipes and ducts. The client and QS are cost-minded, the project manager is time, budget and scope constrained, and the construction manager is delivery and quality concerned. The divergent stakeholders' view makes managing construction activities a herculean task (London & Pablo, 2017; Ngoc Nguyen et al., 2020). The existing traditional model makes it more difficult due to its regimented finish-to-start dominated sequential model. OSC, promisingly, holds the potential to tackle this limitation through early engagement of stakeholders, overlapping work sequence and reaching a compromise without excessive loss of time and money through early design freezing.

With the industry being challenged by a waning workforce population, OSC is not so challenged with large number of skilled workers, those who well understand the basics of OSC methodologies would suffice (Nadim & Goulding, 2010; Shang et al., 2020; R. Zhang et al., 2019a). However, lack of proper coordination and management of the construction downstream sector, perhaps due to a large number of varying workers and the fragmented nature of the industry are contributing issues to OSC Skill workers barrier factor. (Shang, 2019; Alfieri *et al.*, 2020). The industry market which commences with a client and a set(s) of consortiums, does not end at the project completion but extends through another long route of post-construction assessors, then to realtors and end-users and back to maintenance consultants. It is quite a long chain of multi-discipline markets, and it is dictated by too many forces. The

uncertainties that impact the property market and the demand-supply forces of economics in the real estate market are not restricted to traditional buildings alone, they equally play out on OSC projects as well (Jagun et al., 2020; O'Neill & Organ, 2016). What seems good is that with the recent call of the director general of the Confederation of British Industry for building to adopt net-zero buildings to woo the gen-Z towards their properties, OSC posits to become favoured against the market forces (The Telegraph, 2023).

The traditional construction industry business model is defective in fully integrating the OSC method into its practice and policies and so are the planning regulations (J. Goulding et al., 2014; W. Pan et al., 2007b). There seems not to exist a credible business model that comprehensively captures the use of OSC and pre-manufactured solutions. There is also the challenge of adequate resources that would support the transition to satisfy market demands thus tackling the elements contributing OSC business model challenges. The RIBA plan of works have only been recently revised to accommodate MMC practises of category 1-7 (BuildOffsite, 2021).

OSC Knowledge, Communications and Data Management (OSC KCDM): Extant studies observed lack of OSC knowledge and an absence of communication platform(s) as contributing factors inhibiting its wider adoption (Hosseini et al., 2018a; R. Jin et al., 2018). OSC KCDM is observed to be beset by issues such as many of this present generation of construction industry workforce ageing fast (Shang et al., 2020) and some other quite resistant to learning OSC methodology (Razkenari et al., 2020). Other OSC KCDM issues are reluctance of the experienced and ageing workforce to provide knowledge and information to develop technologies that would do the work owing to fear of job loss. Due to the strenuous nature of

the industry jobs, the younger generation is not so encouraged to ‘dirty their bodies’ doing energy-sapping tasks (N. Blismas & Wakefield, 2009; Ginigaddara et al., 2021b; Nadim & Goulding, 2009). Also, present academic curricula in most higher institutions are reported to only be ‘scratching’ OSC at the surface (Nadim & Goulding, 2009). The advocating and regulatory OSC bodies at the moment are largely constrained to rely on further and higher education and experimentation to pass the knowledge of OSC across, rather than tacit experiential knowledge of industry professionals (Darlow et al., 2021; Nadim & Goulding, 2010).

While a handful of literature noted a lack of OSC knowledge as an adoption barrier, some other studies have attributed this lack of knowledge to the absence of records that could provide needed information about proposed or completed OSC projects (R. Jin et al., 2018; W. Zhang et al., 2021). Percentages have been provided as a basis for measuring the adoption level as presented by some firms, but these statistical reports have not presented a robust database or datasets from which their inferences have been drawn. For instance, Hosseini *et al.*, (2018) noted that Europe's use of OSC rose by 40% in 1996 alone aside from the 57% increase in OSC usage as proposed by the UK's largest construction industries, which already were found to have tripled their use of OSC between 2004-2006. Much as this report sounds like the uptake of OSC is gathering the targeted momentum in line with Construction Industry Council's (CIC) 25% OSC usage, the reality on ground is that this analysis does put figure to the actual number of OSC building projects that make up the percentage. Furthermore, industry reports affirm that the said growth accounts for only about 2% of the total buildings constructed and is nowhere near the 25% target (Gan, Chang, Zuo, et al., 2018; Mahat et al., 2019; Nanyam et al., 2017). This study, while gathering the impact of OSC influencing factors contacted major

construction and research institutions within the UK but none could provide any record of information regarding the number of OSC buildings in the UK due to absence of data as observed from the email responses and not necessarily due to data privacies. Industry reports also decry the low use of OSC when compared with the volume of traditional buildings (Heptonstall & Jenkins, 2022). This study gathered that 42 of 72 (over 58%) relevant literature reviewed reported a lack of OSC database as a contributing barrier to the wider adoption of OSC. This is in tandem in the recent report of UK Parliament on OSC progress evaluation in the UK (Ridings, 2024). Relating to the lack of an information database is a communication challenge. While information database is hampered by unavailable project information details on OSC or prefab options and suppliers' alternatives, limited research, under-funded OSC research, OSC data management, loss of schedule information, lack of tools to measure adoption level, use of ethnographic data set, paucity of quality OSC information and insufficient data capture; communication is limited by communication exchange platforms, low use of BIM for projects, communication gap between designers and manufacturers, lack of guidance and information as well as poor information management system.

Attitude: The construction industry has been described to be characterized by an unwillingness (resistance) or having a very slow pace (reluctance) to change (Rahimian et al., 2017; Razkenari et al., 2020). The aged workforce is quite resistant to technological advancement (Adeagbo & Oyemogum, 2019). While some of them are evaluated to be open to giving change a chance, the majority of the older workforce are observed to be very 'anti-change' as observed from extant reports (Nguyen, 2018). The resistance to change has been driven by unionism, local wages and unwillingness to supply domain knowledge to process improvement initiatives and management (Sutrisna, Cooper-Cooke, et al., 2018b). Another driver of their resistance is

fear of job loss. Construction workers think that automating the industry would take their jobs away rather than thinking automation would give room for them to upskill, improve their values and earning capacities (Ginigaddara et al., 2021b).

The industry for instance still manifests extensive low use of BIM at the initial design stage in capturing necessary required data (Alfieri et al., 2020; H. Liu et al., 2021). The transition from an obsolete fabrication approach to a more productive and waste-reducing lean methodology has reportedly been low (Nawari, 2012). The fact that OSC adopts manufacturing process improvement approaches makes OSC suffer similar setbacks to these approaches as experienced in other industries where change policies are being explored. OSC change organization's management and structure thus follow similar trends. The risk-averse nature and dominating traditional idiosyncrasy of the industry are other contributing barriers to the lack of readiness to transit to OSC (Gan, Chang, Zuo, et al., 2018).

A major factor noted to be contributing to OSC attitude barrier is the perceived view end-users hold about prefabricated buildings based on earlier experiences and reports. The majority of those who acquired and used the first set of prefabricated timber houses hold and propagate a negative perception about OSC because of issues relating to leaks, poor material, and weak structure (Gusmao Brissi et al., 2021; Razkenari et al., 2020; X. Zhai et al., 2014). The implication of these experiences is resistance and scepticism about the viability of OSC buildings, leading such clients to making stringent requirements on their briefs when OSC is proposed to them. There is also the issue of customer and end-user satisfaction. The UK RIBA construction framework for example has not reflected adequate post-construction route for measuring building satisfaction by its users (RIBA, 2020). There are also reports of product

recall and its associated cost (T. Lin et al., 2021; I. Y. Wuni & Shen, 2021). This impacts project costs and creates fear of project uncertainties. There are reports also that the appearance of OSC materials does not reflect rigidity and strength like traditional building materials (Lu, Tan, et al., 2021), thus raising questions regarding whether the product material is of quality or not. What must be borne in mind is that huge advances have been made in product materials in all industries to curb excessive consumption of scarce natural resources, minimize waste generated, reduce weight, and meet net-zero carbon emission targets (Tsz Wai et al., 2021). However, this has not eroded the negative perception held by end-users on prefabricated constructions. Summarily, OSC is not another timber prefabricated building characterized by decimation, but an advanced building methodology characterised by improved materials quality and better assemblage techniques.

The least mentioned barrier in the entire review, aside being a make-up of attitudinal factor is OSC awareness (J. Goulding et al., 2014). As noted from the review, this low mention of awareness as a barrier could have stemmed from a ‘perceived’ awareness level existing about OSC. However, the existing awareness level, is domiciled among major industry players and not truly among the larger non-construction industry people as observed from the extensive industry engagement on this review findings. It can, therefore, be arguably understood why lack of awareness has the lowest barrier record among the pieces of literature reviewed. While lack of awareness has not been so much reported as a barrier, extant literature has proposed the need to increase the awareness level through media engagement, stakeholders’ participatory engagements, widening the academic curricula to accommodate more sessions OSC methodology (J. K. Ofori-Kuragu & Osei-Kyei, 2021).

Funding: OSC is a highly capital-intensive venture (W. Pan et al., 2007b, 2008; I. Y. Wuni et al., 2019). OSC funding is a cost-capital-driven influencing factor. Existing studies have demonstrated that cost plays a significant role in how much and how well OSC is adopted (Swarup et al., 2011). While some scholars argue that OSC is more expensive than traditional built construction works, others believe that OSC is, in the long run, more cost-effective than traditional construction and returns on investment are quickly recouped. Some scholars argued further through experimentation that the difference between the construction cost of OSC structures and traditional buildings is negligible (Hui & Khoon, 2020). Some authors reinforced this position by affirming that the cost benefits of OSC cover-up in multiple folds for the obviously small difference in total construction costs (W. Pan & Sidwell, 2011). This should therefore encourage investors and prospective clients not to sway from funding OSC proposals as is currently noticed (Polat, 2010). Some other cost-related issues influencing the wider uptake of OSC are escalating material and labour costs. This is largely dictated by economic and market forces and can be greatly minimized by the early design freeze, procurement selection phase of the project and OSC incentivising policies.

What remains undebated is the fact that a high initial (capital) cost is required to set up an OSC-producing factory (Feldmann et al., 2022; Gusmao Brissi et al., 2021). A good number of scholarly articles that explored barriers to OSC take-off noted initial high cost as a significant barrier (Anvari et al., 2016). This, however, is not different from setting up any other business types. High capital would always be required at the inception stage. What must be borne in mind is that the high initial cost is a one-off cost and what follows thereafter is a running cost. This also, is a common trend in any business. Therefore, the initial high cost is not a ‘super-peculiar’ case to OSC setup alone. Another high initial cost observed is the take-off cost at

project start phase. Unlike the small fraction of total construction cost that is required for mobilization and preliminary at traditional construction project commencement, OSC, because of its factory-production oriented nature, the need to freeze the design as early as possible, selection of a procurement route for the project and the necessity to mobilize the manufacturing company to commence component and module production, calls for a larger chunk of the project cost to be released at the initial project phase. Some scholars estimated the first release to be as high as 70% as against 15%-20% required for traditional projects (W. Pan & Sidwell, 2011). Releasing this high amount of finance at a go may be burdening on project investors.

An emerging funding issue is also noted from the reviews are difficulties in obtaining financing, mortgages, and insurance for OSC projects and buildings (J. K. Ofori-Kuragu & Osei-Kyei, 2021). Studies and reports show that financial institutions hold a negative belief on the quality of OSC building materials as not being strong enough, durable and neither fire resistant (W. Pan et al., 2007b). This puts OSC construction works in the class of high risk and therefore attracts stringent insurance measures and higher financing interests (J. K. Ofori-Kuragu & Osei-Kyei, 2021).

The component and module nature of OSC manufacturing ‘brands’ it as a ‘product-type’ of construction item. This branding allows it to be transacted cross-country. This implies a building can be bought from a manufacturing company in a country and shipped to another location or country where it would be assembled and used. This was the experience with the initial use of prefabricated timber frame houses which were sent from the UK to the USA, Sweden, Australia to mention a few (Thomas, 2006). The cross-country movement of these products has endeared trans-border logistics, which is constrained by complex interfaces

between taxes, duties and bilateral ties between countries. Bendi, (2020) and Ofori-Kuragu & Robert, (2021) observed the trans-border activities related to OSC products also resulted in higher taxes and consequently, higher project cost.

The resultant effect of the cost-capital influencing factor of OSC could further lead to difficulty in achieving an economics of scale regarding the adoption of OSC as a methodology.

Policies and Interventions: Globally, policies determine and shape what we do, how we do them and what goals organizations and governmental bodies set out to achieve (X. Jin et al., 2021; Lye, 2020). The policies set out dictate what regulations would be outlined, as well as what interventions and incentives are required to drive the policies. The world is, at the moment, faced with global warming and housing shortages. Policies are being developed globally to tackle the rising carbon emissions and housing provision. The construction industry has been reported as a major contributor to global warming (Mahat et al., 2019). Policies are being developed within, and for the construction industry to address the impact of the industry on the issue of global warming (J. Goulding et al., 2014). Part of the policies designed is to adopt methods of construction other than the dominating traditional method. This is part of what has led to pushing the idea of OSC on a larger scale aside other potential benefits observed in OSC as earlier noted. However, not all the policies developed are at the moment favouring the wider adoption of OSC (Bendi, 2020b; Jin et al., 2021). Existing regulations are not yet in consonance with some of these policies. Some of these policies do not support local construction codes (I. Y. Wuni et al., 2021b). These discrepancies are inhibiting the wider adoption of OSC.

As earlier noted, policies set out dictate what regulations, interventions and incentives would be provided to drive the policies. While extant studies report that many governmental bodies are putting policies in place to promote OSC adoption in the form of tax rebates, green certification and rating to show their contribution to improving the environment and encourage wider OSC usage, what is also observed is that not all these incentives and interventions are relevant to the wider adoption of OSC (T. Lin et al., 2021). There are also clamours that the interventions and support are not enough, aside not being very relevant.

Environmental Sustainability: OSC has been largely appraised for positively contributing to environmental sustainability by extant research works (Bras et al., 2020). However, some other scholars hold a contrary view on some of the activities of OSC as negatively impacting the environment. For instance, Wang and Sinha, (2021) reported that the carbon emission and energy required in precast concrete which is a form of OSC component is very high. The carbon release, air and noise pollution associated with the transportation of modules and components to the site is quite enormous. Wang (2021) identified transport as the most sensitive element in logistics and the most contributing to carbon emission in the production of prefab elements.

While green certificates have been earlier appraised as an incentive for OSC adoption, not many construction companies get issued green certificates for the use of OSC on their projects. There is also a lack of standardization in measuring the environmental impact of OSC and the issuance of green certificates. Another issue that was noted from the review is that OSC components lack standardization across the board (Razkenari et al., 2020) and end-users satisfaction (Polat, 2010). This gives rise to fear of continuity in the case of insolvency of the production company or contractor.

APPENDIX 4: Interview Call

FACTORS INFLUENCING OFFSITE CONSTRUCTION (OSC)- A UK PERSPECTIVE

The UK construction industry has gone through a couple of revolutions. The building and housing units have equally witnessed everyday review and modification, hoping someday, to get a definite direction in addressing the UK housing challenge. In recent years, there has been global advocacy for a shift in building construction, from traditional construction methods to the Offsite Construction method. But it is observed that there is a relatively low embrace of this advocacy. Many practitioners in the industry are way experienced with the traditional method and are unwilling to change from its use. With a greater number of building projects being completed with the traditional method of construction, there is an obvious fact that the UK building industry is struggling to bring about the wider adoption of OSC within the UK construction industry.

Therefore, the UK Construction Industry Council (CIC) leadership, through its BuildOffsite body, has developed a system to bring together the Cabinet office and Infrastructure & Project Authority in a bid to consolidate the efforts of both bodies in pursuing the goal of wider adoption of OSC. This is aimed at strengthening the ties between the Government and the Construction arm in delivering the annually required homes needed to solve the long-standing UK housing deficit. This is proposed to be achieved through a collaborative approach to

procuring and delivering offsite construction chains, utilizing digitalized manufacturing technologies with a fairer and better-consolidated industry.

The central question around this goal is ‘can OSC assist in delivering these objectives and goals? What underlining factors are responsible for the use of OSC in the UK?’

This survey, therefore, invites you to lend your opinion on the research, which is aimed at identifying the critical drivers and barriers influencing the wider adoption of Offsite Construction, as well as predicting the use of OSC for projects within the UK construction industry. The interview may not directly impact you today, but it is hoped that it would positively impact your environment soon.

Kindly go through the interview questions and consent form to see if you would be willing to grant an interview on the subject matter. It is not compulsory you do take part, but it would be appreciated if you can take it. It would be further appreciated if after taking the interview (or not), you can recommend the interview to someone you know should be willing to take it. The interview call is absolutely voluntary. The interview is very anonymous; therefore any information provided in the course of the interview would be treated with high-level confidentiality.

This study was approved by the University of Hertfordshire Social Sciences, Arts and Humanities Ethics Committee with Delegated Authority (SSAH ECDA) with the Protocol Number BUS/PGR/UH/05327.

NB: Please note that there would be voice (audio) recording of the interview for the sole purpose of capturing details of the interview and transcription from voice to text.

If you, therefore, are willing to be a part of the interview, kindly respond to the call, providing me with a date and time you can be contacted. The interview is expected to last about 45-60 minutes.

Background Information

1. How would you describe your company?
2. Please describe your job role and position in the company.
3. What is your area of specialization in the construction industry?
4. Where is your company located in the UK?
5. Have you and your organization executed any OSC project in the past?
6. Do you think there is sufficient effort to create awareness around the use of Offsite Construction method adoption among construction industry players? How do you rate this level of awareness?

Adoption related information

1. How has the UK construction industry been evolving with the traditional and offsite construction methods? What factors do you think would promote/inhibit the wider adoption of OSC within the UK construction industry?
2. With the emergence of 3D printing in the construction industry, how may Offsite construction thrive in the near future?

Is there any inclusion you would like to make?

Thank you for your time and kind attention. Please feel free to recommend the interview to anyone who could provide information about OSC in the UK.

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APPENDIX 5: Factors identified from Interview Analysis.

S/No	Factors	Respondents	Count	Cluster	Cluster sum	Weight %
1	Logistics	R1	1	Supply Chain Management	19	13.97
2	Transportable designs	R1	1			
3	Ability and capacity of the supply chain industry	R2, R4, R6	3			
4	Undefined pipeline of work (work plan)	R10	1			
5	Transportation (barrier)	R11	1			
6	Installation and logistics management	R12	1			
7	Signing off procurement plan there may be excessive lead time	R12	1			
8	Effective communication	R12	1			
9	Procurement method	R7, R8, R12, R12	4			
10	Supply chain management	R5	1			
11	Site location, access and constrains	R1, R1, R6	3			
12	Suppliers	R2	1			
13	Speed of construction,	R1, R2, R4, R6, R8	5	Time saving	15	11.03
14	Early design resolution and freezing	R2, R4, R8	3			
15	Reducing/improving schedule/programme by 30%,	R3, R8, R12	3			
16	Time saving	R1, R8, R11, R12	4			

S/No	Factors	Respondents	Count	Cluster	Cluster sum	Weight %
17	Efficiency	R1	1	Productivity	14	10.29
18	Productivity	R2	1			
19	Improved working culture and environment	R3	1			
20	Influence of BIM and DFMA	R6	1			
21	Weather	R11	1			
22	Improved process (lean)	R11	1			
23	Waste reduction design	R1, R11	2			
24	Saving overhead	R10	1			
25	Reduction of idle times,	R10	1			
26	Cost of transporting workers,	R10	1			
27	Team cooperation	R4	1			
28	Suitability to project at hand	R4	1			
29	Driving efficiency	R2	1			
30	Historical performance perception	R3, R4, R6, R7	4	Perception	13	9.56
31	People's cultural perception	R3, R4, R7	3			
32	End users (Post occupancy evaluation)	R7	1			
33	Cost perception. (OSC being expensive)	R3, R7, R8, R10	4			

S/No	Factors	Respondents	Count	Cluster	Cluster sum	Weight %
34	Complexity perception	R8	1			
35	OSC buildability	R1	1	OSC Buildability	11	8.09
36	Standardization	R1, R4	2			
37	Building type	R1	1			
38	MEP challenges	R6	1			
39	Methodology adopted for construction	R7	1			
40	The project type	R2, R7	2			
41	The category of OSC is being employed	R2	1			
42	Newness of OSC method	R8	1			
43	Repeatability	R2	1			
44	Delivery and quality control/certainty	R1, R4, R6, R8, R9, R10, R11	7	Improved Quality Performance	10	7.35
45	Sound transfer, insulation and vibrations, thermal properties	R12	1			
46	Better energy performance value	R10	1			
47	Premanufactured target value	R10	1			
48	OSC relevance to construction SME	R3	1	Construction Industry Enterprise	10	7.35
49	Funding approach (tends towards trad building)	R1, R4, R7	3			

S/No	Factors	Respondents	Count	Cluster	Cluster sum	Weight %
50	Fragmentation of the construction industry	R1, R9	2			
51	The marketplace	R2, R9	2			
52	Plans to accommodate SMEs within the construction	R5, R11	2			
53	Cost certainty	R1, R7	2	Cost	9	6.62
54	(Initial) capital cost	R2, R5, R6	3			
55	Financial models	R7	1			
56	Material prices	R6	1			
57	Cost reduction by 30%	R3, R10	2			
58	Less material waste generated	R1, R2, R6, R3	4	Improved Environmental Performance	7	5.15
59	Improve sustainability	R3, R6	2			
60	Net Zero goal	R7	1			
61	Reluctance to change	R1	1	Attitude and Awareness	6	4.41
62	Awareness	R2	1			
63	Construction 2025 paper (published paper in 2013)- with aspiration driving policies, research and awareness)	R3	1			
64	Resistance (private building)	R1, R6, R11	3			
65	Government mandatory regulations	R2, R5, R6,	3		6	4.41

S/No	Factors	Respondents	Count	Cluster	Cluster sum	Weight %
66	Planning system at initiation-early decision-to comply with planning regulations	R8	1	Government interventions		
67	Government policies	R5	1			
68	Support in terms of incentives	R5	1			
69	Projects award in the form of training	R5	1	Education and training	6	4.41
70	Degree of OSC education in institutions	R5, R10,	2			
71	Not much funding for research on OSC	R11	1			
72	Introduction of OSC development prog	R11	1			
73	Lack of education on when and how to use OSC	R8	1			
74	Exempting scaffold and its associated risk	R8	1	Improved Health and Safety	5	3.68
75	Improved Health and safety	R1, R6, R6, R8,	4			
76	Client	R1, R7	2	Stakeholders' influence	5	3.68
77	Early engagement of designers and other stakeholders	R6	1			
78	The need for more housing	R10	1			
79	Early decision to use OSC	R6	1			
	Total		136		136	100

APPENDIX 6: Detailed discussion on Review factors

Drivers:

42 OSC distinct driving factors were identified from two hundred and eighty-nine (289) driving factors mentioned in the 72 viable literature reviewed. 9 aggregating sub-themes emerged from the factors. These sub-themes are Improved Environmental Impact, Time Saving, Improved Delivery Process, Improved Quality Output, improved HSE and Wellbeing, Improved Productivity, Improved Construction Business Management, Improved Cost Management, Government Policies and Interventions, and Supply Chain and Site management. These themes were ranked in the order of the frequency of their mentions in the reviewed articles.

Table 2.1: Summary of OSC Drivers from Literature Review

S/No	Sub-themes	Sub-Theme Count	Theme
1	Improved Environmental Impact	65	Improved Environment and Safety
	Improved HSE and wellbeing	30	
2	Time saving	43	Improved Productivity
3	Improved delivery process	39	
4	Improved Quality output	35	
5	Improved Production rate	23	
6	improved construction business management	22	Construction business and cost management
7	Improved cost management	16	
8	Government Intervention	9	Government Intervention
9	Supply Chain and Site Management	7	Supply Chain and Site Management

Productivity: Transitioning from on-site, labour-intensive methodology of construction into a coordinated and structured factory approach has been reported to add a flavour of productivity to the output. Borrowing a leaf from the manufacturing industry, the construction industry has increased in efficiency and output through employing lean approach, high level consistency, better tolerances in measurements, standardized materials and processes and trade

specialization(J. Goulding et al., 2014). With a frequency count of 43, 39, 35 and 23 observed for time saving, improved process delivery, improved quality output and improved production rate respectively, the productivity theme ranks the most discussed driving factor in the systematic review conducted.

The review indicated that value-added productive transformation to the fragmented conventional construction method (W. Pan & Hon, 2020a) has increased the construction industry production rate (J. X. Zhou et al., 2021a) through application of lean practises (Babalola, Ibem and Ezema, 2019b; Goh and Goh, 2019, 2019; Omotayo, 2014), time saving techniques, improved quality output, resulting in enhanced production rate by integrating value-driven production of both prefab 2D and 3D components. The productivity brought about is not limited to project scheduling and factory output only, but also extends to supply chain, transportation, delivery as well as on-site assemblage (Y. Zhai et al., 2017, 2018b). IoT sensors, RFID and tags have been developed to assist the assembly, installation and positing of the modules or panels rightly and timely. This minimizes probable mistakes that would have resulted in loss of time, efforts and resources (J. X. Zhou et al., 2021a). With automation and large machine application in carrying out tasks, OSC equally has potentials to mitigate the waning construction workforce which is a growing challenge within the industry (Nadim & Goulding, 2009).

Unlike the sequential waterfall approach largely used in construction project delivery where a task is usually completed and approved before the next can be started (I. Wuni, Shen, Robert, et al., 2020), OSC allows for some form of agile and overlapping sequences that do not have to depend on end-to-start sequence of work (Azhar et al., 2013). With construction designs

fabricated early and shop drawings approved, different building or construction segments and components can be produced concurrently and converged at an agreed state, stage or time. They are then coupled together to achieve a part of or the final form to be assembled on site.

A reflection on the state of construction and building materials calls for urgent quality improvement. With rapidly changing climate, there is need for the materials that can shield people from the weather around them to a measurable required standard (Y. Chen et al., 2010). In regions largely exposed to cold like the UK, the quality of materials is required to meet the threshold EPC rating that quite several traditional buildings do not measure up to. Aside meeting climatology benchmarks, the buildings are also expected to perform structurally and aesthetically. Another area that calls for quality delivery in the construction sector is quality of workmanship (J. S. Goulding & Rahimian, 2019). All these values and more can be achieved by moving the process into factor where better-quality control and quality assurance is applied through close inspection, monitoring, and trials. While the conventional method has geared a great deal of efforts on improving material and component quality in recent years, their efforts are betrayed by the unreasonability, inefficiency and errors emanating from poor tradesmen workmanship (human interaction) with near finish state of the project e.g., puncturing a hole in supposed a tight wall or plumbing pipe. This laxity is made up for in factory-oriented approach of OSC (T. Lin et al., 2021) where most activities are automated, and machine executed. Some of the areas that have experienced massive quality improvement under OSC are insulation properties of materials, carbon emission abilities of materials, energy efficiency, moisture and damp resistance of materials, improved functional and structural connections, high consistency, better tolerances, improved whole lifecycle, to mention a few.

Construction industry work is grossly associated with time-wasting activities and speed constraints resulting in delays, extended schedules and project completion dates, request for extension of time (EOT) (C. N. Egwim et al., 2021). The implications of this are usually budget spike and overspending. Some of these delay causing activities may be beyond the control of the project team where it is a force majeure but majority of the time-loss causing activities are traceable to mismanaged human activities (C. Egwim et al., 2022). OSC posits to address this limitation by early design freeze, improved offsite and onsite process, defined procurement routes and well-managed execution schedules. The approach of OSC has been found to have resulted in saving huge project duration period as reported from different projects and research work. (X. Li et al., 2017)

Improved Environment and Safety: There is a global call for improved environment due to the adverse effect climate change is impacting on the universe (Feldmann et al., 2022). Continual discharge of carbon into the atmosphere is negatively impacting the environment with enormous warming, creating fluctuating weather seasons and health challenges (Babalola et al., 2019). The amount of carbon emission released into the environment is traceable to the activities of the construction industry amidst other contributors (S. Wang & Sinha, 2021b). Construction industry is reported to be the second largest industry contributing to global warming (Shi et al., 2017). The acclaimed amount of highly negatively impacting environmental carbon emissions has been found to be closely associated with the activities of traditional construction method both through its embodied and operational carbon emitting activities (GBC UK, 2019). The global population rise calls for increased housing supply which implies increased construction and infrastructure activities on the depleted environment (Alonso-Zandari & Hashemi, 2017). A probable way to reduce the carbon emission escalating

activities is to move the enormous construction activities into the factory, thereby, improvising alternative and less carbon emitting material and process (CITB, 2021).

OSC has been advocated to be more environmentally friendly than traditional method of construction. Improved health and safety, waste reduction, better environmental performance and sustainability were the most frequent factors observed under improved environment and safety with frequency counts of 24, 22, 19 and 10 respectively. The articles admit that OSC method of construction reduces construction waste significantly. Construction waste account for some of the largest industry waste. Majority of this wastes, rather than being recycled or re-used, ends in the landfill. OSC, rather provides room for re-use, recycling and reduction of waste generated rather than discarding such waste in ways that further degenerate the environment.

OSC has also be found to promote sustainability which is in fore front of global meetings and agenda. Aside waste reduction, OSC has been found to lower carbon emission, improve energy efficiency, and encourage deconstructability rather than demolition which creates great nuisance to the environment. Moving construction activities away from site has reduce disruption to site neighbours, reduce onsite incidents which has reached all time reported high records of death, physical injuries, and emotional trauma to those affected by it and their families and keeps sites cleaner.

The use of improved building materials has also been noted to improve living condition of people using OSC building through less energy consumption, less health threatening issues like little or no mould growths, damp issues, leakages, or vegetative growth associated with exterior building edges. The materials also ensure low conduction of winter cold into building thus

keeping users relatively warmer than conventional buildings. Working from factory add a degree of job stability and security to a construction worker who would have had to jump from one job site to the other.

Construction Business and Cost Management: Major phases of traditional construction business are regimented around finish to start task approach because the next phase is dependent upon the completion of the previous phase (Wuni & Shen, 2021). The industry is equally very fragmented and requires a large pool of inter-dependent skills which often do not collaborate effectively (Pan & Hon, 2020a). The consequence of this results in relatively poor management of human and capital resources, slowing down the business activities that could have generated better revenue within a short period of time (Boothman et al., 2014; Ngoc Nguyen et al., 2020). This business approach also makes engaging technological innovation difficult due to resistance from workers (Andersson & Lessing, 2020b; Lessing & Brege, 2015). Adoption of OSC is poised to quick adjustment to accommodating technological advancement and disruption revolutionizing many industries globally, give room for modular scalability, enhance collaboration, mitigate inclement weather and produce better processes and products. This positive potential of OSC would enhance economic and construction industry growth, create opportunities to improve business and project outcomes, and cause minimal negative disruption to construction business.

Rising cost has been identified as one of the major causes of delay, dispute, and litigation within the construction industry business (Pan & Sidwell, 2011; Zhai et al., 2014). Effective cost management in the construction has been reported as one of the reasons for construction industry insolvency (Alaka et al., 2017). Construction industry projects are largely associated

with huge annual and project financial losses. With the construction sector acclaimed to be about the most contributing sector to GDP of countries, insolvency of construction companies implies loss of job and economic downturns. The implications do not end with the construction industries and workers only but extends to the homes and larger populace. With OSC being characterized by defined work scope, early design freeze, early and defined procurement, engagement of relevant stakeholders, reduced project period, a better cost effectiveness and management structure that would reduce cost is introduced into the project scheme. A quicker and better return on investments (ROI) is therefore assured through reduced customary wastage and inflation aversion.

Government interventions: with advocacy for greener environment on the rise globally, many world leaders are lending their voices to the adoption of less carbon emitting activities in the constructions sector. For instance, policies are geared to encourage contractors to embrace OSC and incentives are equally provided to actualize the policies.

Supply chain management: Supply chain and logistics management is one of the most critical segments of construction projects (Wuni & Shen, 2020c; Zhang et al., 2021). Traditional constructions suffer huge setback from supply and logistics failure. Due to tons of different kind of materials needed on site at different stages of the project, delays, mismatch, damage, and losses has been grossly reported on project sites (Daget & Zhang, 2019). Some of the benefits OSC adds to the supply chain segment of construction projects are robust and well-established supply chain systems with minimal type of material and component supply, easy traceability of components through use of advanced traceability technologies like chips, RFIDs, geotags (Chao et al., 2007b; Wang, Wang, Sepasgozar, et al., 2020). OSC has ability to

manoeuvre cranes on constrained sites owing to reduced site activities. Also, OSC requires a smaller number of cranes and crane types on site, thereby reducing conflict-inducing activities (Zhang et al., 2021b).

Conclusively, the driver identified from the SLR, 42 distinct drivers were collated from 289 mentions of drivers. These drivers were aggregated into 9 subthemes which were further grouped into 5 themes. The most frequently discussed theme driving OSC adoption from the set of literature reviewed is productivity with timesaving as the most frequently contributing factor to productivity followed by improved delivery process and improved quality output. This is in tandem with (Nath et al., 2015; W. Pan et al., 2008). The second most frequently discussed issue driving OSC adoption according to the review is improved environment and safety with waste reduction as a factor under improved environmental impact being the most contributing driving factor for OSC adoption. Other emerging influencing issues being observed from the review are construction business and cost management, having potentials to positively influence the adoption process of OSC. Some new but salient factors that may further positively influence the adoption of OSC in the near future if critically appraised are job stability for workers and their wellbeing, better team management, modular scalability of projects and inflation aversion.

2.4.2: Barriers

The emergence and adoption of OSC is faced with several inhibiting factors which a few scholars have termed barriers (Arif et al., 2017b; Schoenborn, 2012) or risks (Sutrisna & Goulding, 2019b; Wu et al., 2019; I. Y. Wuni et al., 2019). OSC barriers have been reported in various forms, types, and categories by extant literature. This study adds credence to the

existing body of knowledge on issues inhibiting the wider adoption of OSC by identifying the nuggets that constitute the building blocks of earlier scholarly identified barriers through a systematic literature review of their works. The review study identified 80 distinct barriers as mentioned in the SLR from 339 barrier mentioned. The barriers were categorized into 15 sub-themes before being aggregated into 8 themes. Not all the sub-themes could be aggregated. Because of the distinctness of some themes, they stood alone, either with large or low number of factors. Some of the most frequently occurring themes constituting major barriers to the wider adoption of OSC are supply chain management, design and construction technology, construction industry management and OSC knowledge and communication with 82, 72, 57 and 48 mentions respectively. Other barrier themes are attitude, funding, policies and interventions and environmental sustainability.

Table 2.2: Identified Barrier Factors Influencing the wider adoption of OSC

S/No	Sub-Themes (Barriers)	Sub-Theme Count	Themes	Themes Count
1	Site logistics and supply chain management	82	Supply Chain Management	82
2	Design Issues	29	Design and construction technology	72
3	Structural Performance	23		
4	Technological Disruption	20		
5	Management technicalities	43	Construction Industry Management	57
6	supportive business model	9		
7	Construction Industry Market	5		
8	Communication and Data Management	42	OSC Knowledge and Communications	48
9	OSC Knowledge	6		
10	Lack of organization readiness to transit to OSC	11	Attitude	32
11	User's Perception of OSC	19		
12	Awareness	2		
13	Funding OSC	20	Funding	20
14	Policies, incentives, and Regulations	19	Policies and interventions	19
15	Environmental Sustainability	9	Environmental Sustainability	9

Supply chain management: Projects are defined as temporary endeavours with a start and finish date. The effective management of a project is critical to its success (Wacker, 1998). Supply chain management is a critical path in the build-up to effective project management amidst other factors like cost, scope, time (Guribie et al., 2022; Mao et al., 2018b). From the selection of procurement route, acquiring material, to transportation and logistics, to delivery, stocking taking and hedging, the supply management determines the timely delivery or failure of project (Y. Zhai et al., 2019b). Supply chain management is not just a challenge in traditional construction, it is a serious challenge in OSC as well considering the nature of the OSC approach (Z. Wang et al., 2019; W. Zhang et al., 2021). Notable among the factors that constitute supply chain challenge to OSC is transportation, production planning and material procurement, capability of the supplying company, logistics and operation with 12, 11, 8 and 7 mentions respectively. Other challenges associated with supply chain management as identified from the literatures are hedging strategies, road size regulations, shape and size of site, access to site, size and shape of modules, managing cranes and other heavy machineries on site.

There are different transportation laws guiding different countries and these laws dictates the sizes of road, and the nature of transportation activities allowed on such roads. For instance, activities allowed or encouraged on trunk A roads are not same as those allowed on access roads. This invariably determines what vehicle sizes are also allowed to ply some routes. Where a site designed for OSC is not directly linked from a reasonably sized road, delivering OSC modules which are associated with reasonably large sizes becomes a challenge (Yang & Pan, 2020; Y. Zhai et al., 2019b). Hoisting and managing lifting cranes on such kind of site would also be a challenge (Z. Zhang et al., 2021b). Suffice to summarize it that the nature, size, and

location of a site greatly influences the adoption of OSC for such site. Other issues bothering around supply chain management are cross boarder logistics (for products not locally manufactured), wrong delivery and availability of local supply (both of labour and material).

Design and construction technology: Scholarly works on OSC described it as both disruptive innovation and a revolutionary approach to construction (Tsz Wai et al., 2021; I. Yahaya. Wuni & Shen, 2019). This implies that OSC do not entirely follow the existing construction paradigms in many ways. Early interview conducted in regards of this study noted that the design of OSC modules requires another approach different from the conventional construction drawings (Laovisutthichai & Lu, 2021). The new approach is termed Design for Manufacture and Assembly, mimicking the manufacturing sector production design approach. A major issue arising from this according to the interview is that majority of architects are not versatile in this design approach, thereby inhibiting the wider uptake of OSC. This cascades into other design issues such as OSC defective designs, dimensional conflicts, tolerance issues, long lead time, changes, creativity-lacking designs, compliance failure as noted from the literature review (N. Blismas & Wakefield, 2009; Jaillon & Poon, 2010; Shang et al., 2020; Sutrisna & Goulding, 2019b).

Prefabricated building has been reported to perform less than anticipated under seismic effect such as earth tremor or earthquake (Savoia et al., 2017; Xiao et al., 2015). In areas highly or lightly susceptible to earth movements, prefabrication has been reported to give way through connection points and joints. Though the UK is an area not susceptible to frequent earth movement or earthquakes, but it reports have it that it does happen and with some significant magnitude. Therefore, adequate joining system must be made safe and stable under seismic

effect and loads. The load supporting ability of prefabricated elements have also been queried by extant studies due to numerous connections required to fit the whole. Researchers attribute this weakness in OSC to inadequate knowledge of assembly and installation techniques required for OSC (Gan, Chang, Zuo, et al., 2018; Hosseini et al., 2018a).

Technology is fast evolving with many improvements to its dynamics and metrics. The industry at large seems not ready for the technological advancement characterizing the adoption of OSC (Qi et al., 2021; M. Wang, Wang, Sepasgozar, et al., 2020). With large number of construction worker accustomed to the rigid sequential manner of construction, OSC is poised to experience a level of resistance arising from quite a number of fears of unknown, ranging from fear of job loss to fear of upskilling or re-skilling (T. B. Balogun et al., 2021; Razkenari et al., 2020). This also has been noted to be a contributory factor to slower OSC adoption.

Construction industry management: Construction industry is heavily fragmented (Z. Wang, Wang, Hu, et al., 2020; I. Y. Wuni et al., 2019). The existing model guiding its activities is highly premised on a task being completed before the next stage could begin. The market structure is dominated by scarce supply to ensure high demand in keeping price values of houses high (Lye, 2020; Rahimian et al., 2017). In a system where global population has been on continual exponential rise, housing shortages reaching all time demands (Bendi, 2020b; Onososen, 2019). The need to sequence an overlapping approach to close the linear sequence of the fragmented industry, revise the dominating traditional model and tone down the short supply market system to keep housing prices up has reached an unprecedented imperative (Babalola et al., 2019; J. S. Goulding & Rahimian, 2019; Martinez et al., 2008). The review of this study indicated management of the construction industry as the second most frequent

mention of the barriers inhibiting the wider adoption of OSC with 72 counts. The review observed management technicalities, lack of supportive business model and construction industry market with 43, 9 and 5 counts respectively as the constituents of this inhibiting theme.

Construction industry is laden with many different stakeholders who hold divergent views on how project should be executed (Tsz Wai et al., 2021; I. Wuni, Shen, & Robert, 2020). For instance, the architects hold the overall look of their structure in high esteem and oftentimes do not want to trade that off for structural functionality of the building and even the functionality of space areas. The Mechanical engineers have been found often at logger heads with the columns and beams of the structural engineers due to passage of pipes and ducts. The client is cost-minded, the project manager is time constrained, and the construction manager is delivery quality concerned. The divergent stakeholders view makes managing construction activities a herculean task (London & Pablo, 2017; Ngoc Nguyen et al., 2020). The existing traditional model makes it more difficult due to its regimented finish to start dominated sequential model. Although, OSC promises to tackle this limitation through early engagement of stakeholders, reaching a compromise without excessive loss of time and money is another challenge.

With the industry been challenged with waning workforce population, OSC is challenged with no good number of skilled workers who well understand the basics of OSC methodologies (Nadim & Goulding, 2010; Shang et al., 2020; R. Zhang et al., 2019a). OSC construction also lacks proper coordination and management of the construction downstream sector, perhaps due to large number of varying workers and fragmented nature of the industry (Alfieri et al., 2020; Shang et al., 2019). The industry market which commences with a client and a set of consortiums, does not end at the project completion but extends through another long route of

post construction assessors, then to realtors and end-users and back to maintenance consultants. It is quite a long chain of multi-discipline market, and it is dictated by too many forces. The uncertainties that impact the property market and the demand-supply forces economics of the real estate market are not restricted to traditional building alone, they equally play out on OSC projects as well (Jagun et al., 2020; O'Neill & Organ, 2016). What seems good is that with the recent call of the director general of confederation of British Industry calling out for building to adopt net-zero building in order to woo the gen-Z towards their properties, OSC may become favoured against the market forces (The Telegraph, 2023).

The traditional construction industry business model is defective in fully integrating OSC method into its practise and policies; so are the planning regulations (J. Goulding et al., 2014; W. Pan et al., 2007b). There seems not to exist a credible business model that comprehensively captures the use of OSC and Pre-manufactured solutions. There is also the challenge of adequate resources that would support transition to satisfy market demands.

OSC Knowledge and Communications: Extant studies observed lack of OSC knowledge and absence of communication platform(s) as contributing factors inhibiting its wider adoption (Hosseini et al., 2018a; R. Jin et al., 2018). The present generation of construction industry workforce, many of whom are aging fast, are quite resistant to learning OSC methodology. They are also reluctant in providing knowledge and information on developing technologies that would do the work owing to fears of job loss. Due to the strenuous nature of the industry jobs, the younger generation are not so encouraged to 'dirty their bodies' doing energy sapping tasks (N. Blismas & Wakefield, 2009; Ginigaddara et al., 2021b; Nadim & Goulding, 2009). The present academic curricula in most higher institutions are reported to only be 'scratching'

OSC at the surface. The advocating bodies are at the moment relying on further education and experimentations to pass the knowledge of OSC across (Darlow et al., 2021; Nadim & Goulding, 2010).

While the existing literature have noted lack of OSC knowledge as an adoption barrier, some other studies have attributed this lack of knowledge to absence of records that could provide needed information about proposed or completed OSC projects (R. Jin et al., 2018; W. Zhang et al., 2021). Percentages have been provided as basis for measuring the adoption level as presented by some firms, this statistical report have not presented a robust database or datasets from which their inferences have be drawn. For instance, (Hosseini et al., 2018a) noted that Europe use of OSC rose by 40% in 1996 alone aside the 57% increase in CSC usage as proposed by UK largest construction industries, who already were found to have tripled their use of OSC between 2004-2006, much as this report sounds like the uptake of OSC is gathering momentum, the reality on ground is that this analysis does put figure to the actual number of OSC buildings that make up the percentage. Furthermore, industry reports affirms that the said growth account for only about 2% of building constructed (Gan, Chang, Zuo, et al., 2018; Mahat et al., 2019; Nanyam et al., 2017). This study, while gathering impact of OSC contacted major construction and research institutions within the UK but none could provide any record of information regarding the number of OSC building in the UK, perhaps due to data privacy policies. Industry reports rather decry the low use of OSC when compared with the volume of traditional buildings. This study gathered that 42 of 72 literature reviewed reported lack of OSC database as contributing factor to the wider adoption of OSC. Relating to lack to information database is communication challenge. While information database is hampered by unavailable information on OSC or prefab options and suppliers' alternatives, limited research, OSC data

management, loss of schedule information, lack of tools to measure adoption level, use of ethnographic data set, paucity of quality OSC information and insufficient data capture; communication is limited by communication exchange platforms, low use of BIM for projects, communication gap between designers and manufacturers, lack of guidance and information as well as information management system.

Attitude: Construction industry has been described to be characterized with unwillingness to (resistance) or having very slow pace (reluctance) to change (Rahimian et al., 2017; Razkenari et al., 2020). The aged workforce is quite resistant to technological advancement (Adeagbo & Oyemogum, 2019). While some of them are evaluated to be opened to giving change a chance, majority of the older workforce are observed to be very ‘anti-change’ as observed from the interview reports. The resistance to change has been driven through unionism and unwillingness to supply domain knowledge to process improvement ideas and management. Another driver of their resistance is fear of job loss. They are of the opinion that automating the industry would take their jobs away rather than thinking automation would give room for them to upskill and improve their values and earning capacities (Ginigaddara et al., 2021b).

The industry for instance still manifest extensive low use of BIM at initial design stage in capturing necessary required data (Alfieri et al., 2020; H. Liu et al., 2021). The transition from obsolete fabrication approach to more productive and waste reducing lean methodology has reportedly been low. The fact that OSC adoption gives room for these process improvement approaches makes OSC suffer similar setbacks these approaches has suffered. The organization management and structure follow similar trends. The risk averse nature and dominating

traditional idiosyncrasy of the industry are other contributing factors to lack of readiness to transit to OSC (Gan, Chang, Zuo, et al., 2018).

A major factor contributing to OSC attitude barrier is the view perceived end-users hold about prefabricated building based on earlier experiences and reports. Majority of those who acquired the first used prefabricated timber houses hold a negative perception about OSC because of issues relating to leaks, poor material, and weak structure (Gusmao Brissi et al., 2021; Razkenari et al., 2020; X. Zhai et al., 2014). The implication of these experiences are resistance and scepticism about the viability of OSC buildings, leading to such clients making stringent requirements on their briefs when OSC is proposed to them. There is also the issue of customer and end-users' satisfaction. The UK RIBA construction framework for example has not reflected adequate post-construction route for measuring building satisfaction by its users (RIBA, 2020). There are also reports of product recall and its associated cost (T. Lin et al., 2021; I. Y. Wuni & Shen, 2021). This impacts project cost and creates fear of project uncertainties. There are reports also that the appearance of OSC materials do not reflect rigidity and strength like traditional building material, thus raising questions regarding whether the product material is of quality or not. What must be borne in mind is that huge advances have been made on product materials in all industries to curb excessive consumption of scarce natural resources, minimize waste generated, reduce weight, and meet net-zero carbon emission targets. Summarily, OSC is not another timber prefabricated building characterized by decimation, but an advanced building methodology characterised by improved quality materials and better assemblage techniques.

The least mentioned barrier from the entire review is lack of OSC awareness (J. Goulding et al., 2014). As argued from the interview, this low mention of awareness as a barrier could have stemmed from a 'perceived' awareness level existing about OSC. The awareness level is domiciled majorly among industry players and not truly among the larger non-construction industry people. Therefore, it can be arguably understood why lack of awareness has the lowest barrier record among the literatures reviewed. While lack of awareness has not been so much reported as a barrier, extant literature has proposed the need to increase the awareness level through media engagement, stakeholders' participatory engagements, widening the academic curricula to accommodate more sessions OSC methodology.

Funding: OSC is a high capital-intensive venture (W. Pan et al., 2007b, 2008; I. Y. Wuni et al., 2019). OSC funding is a cost-capital driven influencing factor. Existing studies has demonstrated that cost plays significant role is how much and how well OSC is adopted (Swarup et al., 2011). While some scholars argue that OSC is more expensive than traditional built construction works, others belief that OSC is in the long run, more cost effective than traditional construction and returns on investment are quickly recouped. Some scholars argued further through experimentation that the different between the construction cost of OSC structures and traditional building is negligible (Hui & Khoon, 2020). The authors also reinforced this position by affirming that the cost benefits of OSC cover up in multiple folds for the obviously small difference in total construction costs. This therefore provides encouragement for investors and prospective clients not to sway from funding OSC proposals. Some other cost related issues influencing the wider uptake of OSC are escalating material and labour cost. This is largely dictated by economic and market forces and can be greatly minimized by early design freeze and procurement selection phase of the project.

What has not been debated is the fact that a high-initial cost is required to set up an OSC producing factory (Feldmann et al., 2022; Gusmao Brissi et al., 2021). A good number of literatures that explored barriers to OSC take off noted initial high cost as a significant barrier (Anvari et al., 2016). This, however, is not aliened to setting up any other business types. High capital would always be required at the inception stage. What must be borne in mind is that the high initial cost is a one-off cost and what follows thereafter is a running cost. This, also, is a common trend in any business. Therefore, initial high cost is not a ‘super-peculiar’ case to OSC set up alone. Another high initial cost is what is observed at the take-off of the project phase. Unlike the small fraction of total construction cost required more mobilization and preliminary at project commencement, OSC, because of its factory-production oriented nature, the need freeze the design as early as possible and select a procurement route for the project and the necessity to mobilize the manufacturing company to commence component and module production calls for larger chunk of the project cost to be released at the initial project phase. Some scholars estimated the first release to be as high as 70% as against 15%-20% required for traditional projects. Releasing this high amount of finance at a go maybe burdening on project investors.

An emerging funding issue being reported from the interview and upheld by the interviewees is that there are difficulties in obtaining financing, mortgage, and insurance for OSC projects and buildings. Studies and reports show that financial institutions hold a negative belief on the quality of OSC building materials as not being strong enough, nor durable and neither fire resistant. This puts OSC construction works in the class of high risk and therefore attracting stringent insurance measure and higher financing interests. It has therefore become difficult obtaining financial services for OSC proposals, especially following the incidence of Grenfell

towers which was razed and requires reconstruction unlike the Irish law building whose structure stood after being consumed by fire and requires basically renovations.

The component and module nature of OSC manufacturing brands it as a ‘product-type’ of construction item. This branding allows for it to be transacted cross-country. This implies a building can be bought from a manufacturing company in a country and shipped to another location or country where it would be assembled and used. This was the experience with the initial use of prefabricated timber frame house which were sent from UK to USA, Sweden, Australia. The cross-country movement of these products has endeared trans-border logistics, which is constrained by complex interfaces between taxes, duties and bi-lateral ties between countries. (Bendi, 2020b; Ofori-Kuragu & Robert, 2021) observed the trans-border activities related to OSC products also resulted in higher taxes.

The resultant effect of the cost-capital influencing factor of OSC could further lead to difficulty in achieving an economics of scale regarding the adoption of OSC as a methodology.

Policies and interventions: Globally, policies determine and shape what we do, how we do them and what goals organizations and governmental bodies set out to achieve (X. Jin et al., 2021; Lye, 2020). The policies set out dictates what regulations would be outlined, as well as what interventions and incentives is required to drive the policies. The world is, at the moment, faced with global warming and housing shortages. Policies are being developed globally to tackle the rising carbon emission and housing provision. Construction industry has been reported as a major contributor to global warming (Mahat et al., 2019). Policies are being developed within the construction industry to address the impact of the industry on the issue of global warming (J. Goulding et al., 2014). Part of the policies designed is to adopt other

measures of construction other than the dominating traditional method of construction. This is part of what has led to pushing the idea of OSC on a larger scale aside other potential benefits observed in OSC. However, not all the policies developed are at the moment favouring the wider adoption of OSC (Bendi, 2020b; X. Jin et al., 2021). Existing regulations are not yet in consonance with some of these policies. Some of these policies do not support local construction codes (I. Y. Wuni et al., 2021b). These discrepancies are inhibiting the wider adoption of OSC.

As earlier noted, policies set out dictates what regulations, interventions and incentives would be provided to drive the policies. Extant studies report that many governmental bodies are just not putting policies in place to adopt OSC, they are also providing incentive and interventions in the form of tax rebate, green certification and rating showing their contribution to improving the environment, consideration to bid for some kind of big projects. What is also observed is that not all these incentives and intervention are relevant to the wider adoption of OSC (T. Lin et al., 2021). There are also clamours that the interventions and support are not enough, aside not being very relevant.

Environmental sustainability: OSC has been largely appraised for positively contributing to environmental sustainability by extant research works (Bras et al., 2020). However, some other scholars hold a contrary view on some of the activities of OSC as negatively impacting the environment. For instance, Wang and Sinha, (2021) reported that the carbon emission and energy required in precast concrete which is a form of OSC component is very high. The carbon release, air and noise pollution associated with the transportation of modules and components to the site is quite enormous. Wang (2021) identified transport as the most sensitive element in

logistics and the most contributing to carbon emission in the production of prefab elements. While green certificates have been earlier appraised as incentive for OSC adoption, not many construction companies get issued green certificates for use of OSC on their projects. There exist also lack of standardization in measuring the environmental impact of OSC and the issuance of green certificates. Another issue that was noted from the review is that OSC components lack standardization across board (Razkenari et al., 2020). This gives rise to fear of continuity in the case of insolvency of the production company or contractor.

APPENDIX 7: Detailed Content Analysis Discussion

S/ No	Factors	Respondents	Count of Mentions by Respondent	Total Respondents' Counts	Weight of respondents' counts (%)	Clusters	Factor Count	Weight of Factor counts (%)
1	Logistics	R1	1	19	13.97	Supply Chain and Logistics	12	15.19
2	Transportable designs	R1	1					
3	Ability and capacity of the supply chain industry	R2, R4, R6	3					
4	undefined pipeline of work (work plan)	R10	1					
5	Transportation (barrier)	R11	1					
6	Installation and logistics management	R12	1					
7	<i>Signing off procurement plan there may be excessive lead time</i>	R12	1					
8	Effective communication	R12	1					
9	Procurement method	R7, R8, R12, R12	4					
10	Supply chain management	R5	1					

S/ No	Factors	Respondents	Count of Mentions by Respondent	Total Respondents' Counts	Weight of respondents' counts (%)	Clusters	Factor Count	Weight of Factor counts (%)
11	Site location, access and constrains	R1, R1, R6	3	15	11.03	Time saving	4	5.06
12	Suppliers	R2	1					
13	Speed of construction,	R1, R2, R4, R6, R8	5					
14	Early design resolution and freezing	R2, R4, R8	3					
15	Reducing/improving schedule/programme by 30%,	R3, R8, R12	3					
16	Time saving	R1, R8, R11, R12	4	14	10.29	Productivity	13	16.46
17	Efficiency	R1	1					
18	Productivity	R2	1					
19	Improved working culture and environment	R3	1					
20	Influence of BIM and DFMA	R6	1					
21	Weather	R11	1					
22	Improved process (lean)	R11	1					
23	Waste reduction design	R1, R11	2					
24	<i>Saving overhead</i>	<i>R10</i>	1					
25	<i>Reduction of idle times,</i>	<i>R10</i>	1					

S/ No	Factors	Respondents	Count of Mentions by Respondent	Total Respondents' Counts	Weight of respondents' counts (%)	Clusters	Factor Count	Weight of Factor counts (%)
26	Cost of transporting workers,	R10	1	13	9.56	Perception and Attitude	5	6.33
27	Team cooperation	R4	1					
28	Suitability to project at hand	R4	1					
29	Driving efficiency	R2	1					
30	Historical performance perception	R3, R4, R6, R7	4	11	8.09	OSC Buildability	9	11.39
31	People's cultural perception	R3, R4, R7	3					
32	End users (Post occupancy evaluation)	R7	1					
33	Cost perception. (OSC being expensive)	R3, R7, R8, R10	4					
34	Complexity perception	R8	1	11	8.09	OSC Buildability	9	11.39
35	OSC buildability	R1	1					
36	Standardization	R1, R4	2					
37	Building type	R1	1					
38	MEP challenges	R6	1					
39	Methodology adopted for construction	R7	1					
40	The project type	R2, R7	2					

S/ No	Factors	Respondents	Count of Mentions by Respondent	Total Respondents' Counts	Weight of respondents' counts (%)	Clusters	Factor Count	Weight of Factor counts (%)
41	The category of OSC is being employed	R2	1					
42	Newness of OSC method	R8	1					
43	Repeatability	R2	1					
44	Delivery and quality control/certainty	R1, R4, R6, R8, R9, R10, R11	7	10	7.35	Quality Performance	4	5.06
45	Sound transfer, insulation and vibrations, thermal properties	R12	1					
46	Better energy performance value	R10	1					
47	Premanufactured target value	R10	1					
48	OSC relevance to construction SME	R3	1	10	7.35	Construction Industry Enterprise	5	6.33
49	Funding approach (tends towards trad building)	R1, R4, R7	3					
50	Fragmentation of the construction industry	R1, R9	2					
51	The marketplace	R2, R9	2					

S/ No	Factors	Respondents	Count of Mentions by Respondent	Total Respondents' Counts	Weight of respondents' counts (%)	Clusters	Factor Count	Weight of Factor counts (%)
52	Plans to accommodate SMEs within the construction	R5, R11	2					
53	Cost certainty	R1, R7	2	9	6.62	Cost	5	6.33
54	(Initial) capital cost	R2, R5, R6	3					
55	Financial models	R7	1					
56	Material prices	R6	1					
57	Cost reduction by 30%	R3, R10	2					
58	Less material waste generated	R1, R2, R6, R3	4	7	5.15	Environmental Sustainability	3	3.80
59	Improve sustainability	R3, R6	2					
60	Net Zero goal	R7	1					
61	Reluctance to change	R1	1	6	4.41	Awareness	4	5.06
62	Awareness	R2	1					
63	Construction 2025 paper (published paper in 2013)- with aspiration driving policies, research and awareness)	R3	1					
64	Resistance (private building)	R1, R6, R11	3					
65	Government mandatory regulations	R2, R5, R6,	3	6	4.41		4	5.06

S/ No	Factors	Respondents	Count of Mentions by Respondent	Total Respondents' Counts	Weight of respondents' counts (%)	Clusters	Factor Count	Weight of Factor counts (%)
66	Planning system at initiation-early decision-to comply with planning regulations	R8	1			Government Policy and Interventions		
67	Government policies	R5	1					
68	Support in terms of incentives	R5	1					
69	Projects award in the form of training	R5	1	6	4.41	OSC Knowledge	5	6.33
70	Degree of OSC education in institutions	R5, R10,	2					
71	Not much funding for research on OSC	R11	1					
72	Introduction of OSC development prog	R11	1					
73	Lack of education on when and how to use OSC	R8	1					
74	Exempting scaffold and its associated risk	R8	1	5	3.68	Health and Safety	2	2.53
75	Improved Health and safety	R1, R6, R6, R8,	4					
76	Client	R1, R7	2	5	3.68		4	5.06

S/ No	Factors	Respondents	Count of Mentions by Respondent	Total Respondents' Counts	Weight of respondents' counts (%)	Clusters	Factor Count	Weight of Factor counts (%)
77	Early engagement of designers and other stakeholders	R6	1	136	100	Stakeholders' influence	79	100
78	The need for more housing	R10	1					
79	Early decision to use OSC	R6	1					
			136	136	100		79	100

APPENDIX 8: Detailed Thematic Analysis Discussion

Findings and Discussions:

Awareness: The research found that awareness level is one of the major factors influencing the wider adoption of OSC within the UK construction industry. This agrees with earlier research works carried out by (Hosseini et al., 2018a). This study however delved further on the issues bothering around awareness and discovered that within the UK construction industry, there exist some reasonable level of awareness as reported by majority of the interviewees.

"I would say there's a lot of awareness. There's a lot of publications. There's a lot of conferences. There's a lot of discussion. Several Companies have established modern method of construction departments and divisions within their companies, and so in terms of awareness, I think there is a large awareness that exists"- R6

"Hey, I can see there are lot of information in this space regarding this, and I think it's driving it down to the grassroots."- R5

However, the level of awareness existing is dominant among the construction industry players. Another important note observed is that the present awareness level has not translated into adoption. The few who know about OSC have not fully adopted it.

R5 further noted that:

"And the industry is same. It's getting a lot of information, a lot of publication out there; we now have what we call the categories of offsite the. So, it's a lot

of information are coming out into the industry regarding this approach.

Currently, I can say that a lot of information is out there. "- R5

R4 shares same view with earlier quotes but added that awareness does not imply adoption.

"I think there is plenty of efforts going on to make awareness of offsite construction. Uhm, whether everybody listens to it is another matter."- R4

Therefore, some of the interviewees proposed recreating and increasing awareness among the general populace as probable solutions to increasing the adoption possibilities of OSC. This also is in agreement with the proposition of (Hosseini et al., 2018a)

"I believe that the best way to make this industry change is to showcase examples of success through innovation or change....And I think once we can demonstrate really good examples of successful innovation, that's how the industry will change. So for me this is an amazing opportunity"- R2

In the view of the respondents, offsite construction is not alien to the UK construction industry. (Hosseini et al., 2018a) noted that Europe use of OSC rose by 40% in 1996 alone aside the 57% increase in CSC usage as proposed by UK largest construction industries, who already were found to have tripled their use of OSC between 2004-2006. Much as this report sounds like uptake of OSC is gathering momentum, but the reality on ground is that this analysis does put figure of the actual number of OSC buildings that make up the percentage. This study, while gathering impact of OSC contacted major construction institutions within the UK but none could provide any record of information regarding the number of OSC building in the UK. Industry reports rather decry the low use of OSC when compared with the volume of traditional

buildings. OSC projects were found to be as low as 5% of entire construction projects annually.

In fact, some interviews scored the awareness level below 5 on a rating of 10.

"In terms of awareness, probably low...and 2/10 at the very best " -R1

"OK, I mean the level of awareness is relatively low. You know that's why I said for 4/10. And the level of adoption is within most of the major players within the construction industry." - R12

Therefore, while a lot of efforts required in bringing to the consciousness of people, the existence of OSC through publications, discussions, conferences, and sorts, it emerged from the interviews that effort is geared towards driving this awareness to the very grassroots and that willingness to make use of the information on OSC solely rests with the people fed with such information as noted by R4.

However, some interviewees felt that the awareness created around the use of OSC construction within the UK construction company is not yet sufficient to drive the desired adoption level.

R12 further commenting, observed the need for increased level of awareness.

"We really need more awareness within the industry for offsite construction, so you know not only to save time but to improve quality of construction products as well, being done in an enclosed and properly managed area as well." R12

It was observed that some of the respondents differed in opinion on the awareness level as not being so low as observed by R12 and R1.

"I think offsite construction is becoming a more noticeable idea, more people are aware of it. And even in the 10-15 years since I was working extensively and designing offsite solutions, I think nowadays it far more common solution..."- R2

Rather, the existing awareness has not translated into adoption. These points established that awareness on OSC exists, and the average awareness level is not low, though adoption is low.

"... I think people know about it. I'd say 9 for that. I think they know about it."- R11

"I mean offsite level of awareness is probably 7 or 8, but the problem is what people do with that awareness. Are they going to actually act on it and actually implement? That's a difficult thing."- R4

Some of the respondents also pointed out that the existing awareness on OSC within the UK construction industry is domiciled majorly among the industry professional and not necessarily with the industry product end users. R6 gives an insight on the difference between construction and non-construction people's awareness on OSC.

"In terms of the consultant chain, so architect, engineers and you know, structural engineers and MEP. So, there's much more awareness there, but you

have seen historically, I think, particularly actually in residential...low use..."-

R8

"... I'm not sure that my friends that are not in the construction industry have much awareness of modern methods of construction, I'm not sure my circle of friends who are not in the construction industry have a true awareness of how things are done. OK?"- R6

Some other respondents (R8 and R4) posits that the next bulk of people that know so much about OSC are the industry stakeholders. This further upholds the view that awareness is majorly among the construction industry players.

"I think there's a lot. There's a lot of awareness. And obviously, some of the bigger players in the wider construction industry who operate across multiple sectors have been transferring skills between those sectors historically." - R8

"Yeah, I got. I think... let's reflect on what I said at the beginning about when they go to conferences, you tend to see the same kind of people all the time. Would they invite person not in-houses in? I don't know. Maybe, maybe not"- R4

The submissions above are pointers that there exist a gap between the industry players (manufacturers and professionals) and the product consumers- the end users. The OSC knowledge therefore needs to be diffused beyond the boundaries of just the industry professional and stakeholders for it to gain wider acceptance as noted by R9 and R12.

“Getting people focused on the big picture, on why the adoption is being made a constant reminder. Introducing training for construction employees as well.”- R12

"Earlier on, within the design stage, I would say there is not enough awareness within the industry for people to feel confident in approaching a design with offsite from the beginning to make sense."- R9

Despite the aforementioned shortcomings regarding the awareness of OSC in the United Kingdom, the respondents also appraised the efforts geared towards increasing the visibility of OSC by its crusaders. They noted that:

"This is getting better. People are beginning to understand that, obviously as the training that the supply chain school have developed as being...they've taken more and more people than they were expecting. Awareness is growing. I think the actual level of offsite construction is higher than perhaps anticipated."- R1

"...and the barriers I think they're slowly dissipating really, like more and more people realize that we need to use modern methods of construction..."- R11

Some of the respondents also gave insights as to how OSC awareness could be expanded through recreating the awareness methods. Some of the suggested approaches to widening OSC reach is by publicizing the successes achieved with OSC and creating more training where

OSC methodology could be better communicated to construction workers and potential workers.

"I believe that the best way to make this industry change is to showcase examples of success through innovation or change...And I think once we can demonstrate really good examples of successful innovation, that's how the industry will change. So, for me this is an amazing opportunity"- R2

"...and of course, the training providers I belong to- a group with called offsite alliance, and we are looking at passing this information, not just to decrease...but to the improve. We're looking at Level 3, so those in colleges, so we have a task force who are going to colleges, talking to them about modern method of construction"- R5

Some respondents are also of the view that a major point to note is that existing awareness level of OSC is not translating to a corresponding level of adoption.

"...I'm not sure that it's kind of getting to everybody, and maybe it is getting to the 95% but they just choose not to use it. They think they're quite happily doing things in traditional ways. So it's not an easy question to answer."- R4

Awareness can be defined as having knowledge about the existence of an object, item or issue while adoption can be said as accepting to use or employ the object, item or issue in addressing a problem or conducting a task. Therefore, approach need to be redesigned to ensure that the 'talking' and 'knowing' becomes the 'doing' as pointed out by R6 and R9.

"And I would say, ... I would say people are aware of them. But I think are scared to make the decision to use them until it's a contractor led decision..."-

R9

"Whether there's enough pragmatism about how you can actually then apply it is another question, but uhm, but in terms of awareness, I think yes, the industry is very aware of modern methods of construction offsite and the different techniques that can be used." - R6

This study further queried the interviewees to know ascertain the claim made by some interviewees on the low level of adoption in relation to the awareness created around OSC. R7 noted that:

"Half of the adoption, maybe less to be honest, but I don't know. But it's quite low. The adoption is quite low." - R7

Examining the opinion of the interviewees on the level of OSC adoption within the UK construction industry in relation to existing awareness, respondents who could speak on the adoption level based on their knowledge of it, all rated the adoption level below 5. This view justifies the essence of this study as very needful at this time. More importantly, it provided basis for the qualitative reasons for this study.

"Yeah, adoption maybe three or four (out of 10)." - R10

"Ah, I think that's more 4 out of 10." - R11

"On a scale of 1 to 10, I would say we are probably on about 4 / 10. Yeah, that's...that's what I give you. I think there's still a lot to be learned and still..."-

R12

On a flip of the coin, the respondents appraised the adoption level as having improved in recent years and that the desire of the industry to explore OSC as method of constructing building and structures has increased.

"I think it is evolving, but as I mentioned before, I think it's only evolving in pockets..."- R4

"Well, I was at a committee really and it goes back to what I said earlier about the way this industry seems to have an appetite for change that it never used to have, so you know, all through my career I've worked under..."- R2

As noted by R7, policies by the government and construction industry have been helping increase OSC awareness and consequently drive the adoption of OSC. These further addresses one of the objectives of this research on how to remove the barriers inhibiting the wider adoption of OSC and encourage the drivers.

"They have come up with a statement in the press that they're looking for at least 50% of the apartment blocks they build going forward to be built with offsite construction. So as these major builders start to adopt offsite construction, then the awareness grows"- R7

Another area of concern influencing the wider adoption of OSC as touched on by the interviewees is quality.

Quality: Quality, as identified by majority of extant literature by researchers who have attempted to unravel the influencing factors of OSC has been largely adjudged a driver- and one of the prominent ones driving OSC adoption. The finding of this study as revealed by the interviewees agrees with the paradigm that quality is one of the positive factors driving the wider adoption of OSC globally. Three (3) building blocks to quality factors were identified in this study by just three (3) interviewees. They are quality improvement, controlled production environment and quality control.

Perception: There exists a lot of preconceived ideas on OSC. The re-introduction of OSC into the constructions industry has garnered several reactions and dispositions from professionals, stakeholders, and end-users as a result of different experience they had when prefabricate buildings were first tried. These experiences created perceptions which today influence the wider adoption of OSC within the UK construction industry and the globe at large. This study gathered that Quality perception, Attitudinal perception, Monotonous perception, cost perception and historical (cultural) perceptions are the building blocks constituting the perception influencing factor.

Some of the respondents noted that the public holds a perception that an OSC buildings do not offer quality as high as what is experienced with traditionally constructed buildings while others hold the view that there has been improvement and the negative quality perception is not as it used to be.

"But so, so I think it's kind of quite variable. I still think there is probably this perception that kind of prefab is kind of not as good as bricks. I still think there is a perception, but. I think it's kind of changing"-R4

" Second one, I think there is a perception still that offsite is kind of rubbish. We still have this preconception about prefab, prefabricated dwellings or buildings, that sort of came about through the 20th century, and there were a lot of failures. And with Offsites, not only in technical failures to deal with even though, failures in concrete or watertightness and things like that... but there are, there are not. But just to kind of, general quality was not good. I think it kind of arrived before its time and was not done in a kind of proper quality, assured or manufactured way. So, so there's this general cultural perception that offsite it's rubbish, and that house built of bricks are better"- R4

Some other interviewees debunked the opinion that OSC is of less quality than traditionally constructed building with the view that it is just a thing of perception, and the users need to look beyond their prior idea of what a prefab building used to be.

"There is a perception, I think, public perception, perhaps that volumetric modular offsite is not as good quality as traditional build, but I don't think that that's true at all. So, it's a perception problem"-R2

"The perception is all offsite construction may not meet the standard. Why would it not meet the standard? the material using north side is timber, wood, steel."- R5

The re-emergence of OSC has brought about varying attitudinal reactions by people within and outside the construction industry. The interviewees noted that such attitudinal reactions include fear of job loss, a mixed reaction of resistance, improved product, and willingness to try out OSC product and its methodology.

"Ah, yeah, yeah, it's interesting, so a lot, yeah, so people might think that if you automate things more that people will lose jobs and because there's less manual work to do"-R11

Another responder shared a different view where the construction workers were pushing for the use of OSC, perhaps, due to the benefits they might have seen using it on past projects even when the responder who probably is the lead professional on the project may have been sceptical embracing OSC.

"I don't know, I'm afraid. I've had the only project that I've worked with really... the construction workers were on board and keen to use the methodology that we had. But that's because they were pushing for it as well. So, that's the only exposure I've had is that they were keen for it."-R9

R10 submitted that there is a willingness to use OSC within the industry despite the fears and reluctance among many.

"I think there is a willingness to accept the modern methods of construction."-R10

There is also the perception that OSC buildings doesn't give room for design ingenuity and creativity, thereby resulting in monotonous buildings. The view is shared with a mixed expression by the interviewees. The interviewee R9 when asked his opinion of how applicable OSC is to design creativity as part of the follow up question noted that:

"I do think so. I think it needs to be. It's important that it is. I think there's a perception that it needs to just be boxes stacked boxes, but I'm... you know it, it's components. Its offsite construction doesn't mean Uh, you're designing the whole building. It's not the whole thing, and it's parts. Parts of the building which are all coming together in components so you know you can assemble these components in a number of ways."- R9

Another view perceived by people on OSC as observed by the respondents is that OSC costs much more than traditional building and this is having a strong influence in deciding whether or not to use OSC. The deficiency of this view is that the cost is not appraised beyond the construction cost.

"I think this is very often driven by cost and the cost consultants. I mean this comes up time and again when you're actually evaluating whether or not offsite construction is actually appropriate. The said people will look at the actual cost comparison and they look at the sort of construction cost, but they won't look at the wider value" R1

R7 provided a hint on how to help people with cost perception on OSC by addressing it through a change of mind approach which may be driven effectively through heads of construction businesses.

"They just look at the quotation from the offsite construction quotation from the traditional constructor and say offsite is too expensive, we'll stick to what we know. We need to get people's mindset to change, and that's the challenge. How do we get people mindset to change. And I genuinely believe that can only come from the top of the businesses"- R7

OSC has got a long history of use when it was first employed in the re-settlement scheme of returning armies after World War II in the 1800 (Baron, 1983; Thomas, 2006). While its quick assemblage and delivery time were a motivating factor, its short-span service became a menace that lingers on in people's mind. Its history has today left people with the worry of whether to use OSC again.

"World in action was a program on ITV in the UK. Well, it actually used to explore stories that were controversial. And they heard about problems with timber frame construction...Yeah, and how this stuff where they hadn't been built improperly.... and that decimated the UK timber frame, well, the English timber frame industry and it's taken them many, many years to rebuild. So, it goes through cycles this offsite construction"-R7

Today, there a great work to do in re-orienting people on the values OSC presents in this modern age and how efficiently it is, just like, if not better than traditional buildings.

"I think if you take the residential sector initially, it's getting people to understand and recognize that factory-built apartment is just as good as one that's actually built traditionally."- R1

Attitude: The historical records of earlier use of prefabricated buildings have left users of OSC methods with different attitudes and inclinations (Nanyam et al., 2017; W. Pan et al., 2008). While some are eager to embrace OSC, some others are still sceptical about the use of OSC for projects. This study shows three (3) building blocks to attitude influencing factor of OSC. The building blocks are Reluctance and Resistance to change, Preference for well-known Traditional Method (conservatism) and Fear of unknown (protectionism).

The construction industry as depicted by many extant literatures is reported as being averse to technology adoption and introduction of new construction methodologies (Arif et al., 2017a; Gan, Chang, Zuo, et al., 2018). Many of the industry players are observed to be conservative in nature regarding new introductions into the industry (W. Pan et al., 2007b). The revival of OSC has been welcome by a degree of resistance as reported by the interviewees. However, there has also been a desire to accommodate change in recent times.

"I build quickly and make a lot of money. Why should I change to steel frame or timber frame or volumetric modular? Why should I change? I've always done it this way. It works for me and that a lot of time. It is the challenge. It's the old school thinking, so it's the senior staff have been around for far too long. We've always done it that way. And for offsite to really grow, it needs a mindset change with some of the senior people in these businesses. And the only way that happens is for them to see the benefits "- R7

As noted by R7, R2 and R12, the resistance experienced has been found to be dominant among the older members of the industry.

“And bits of restraint from, you know, from older practitioners within the industry. You know we can’t beat them to it...they’ve been very used to the traditional method of construction...”- R12

"I've come to the conclusions. It's probably age related. I've got friends and colleagues who've been in the industry as long as me, and even today, resist change. They don't like digital technology, and they don't like modern methods of construction because they had careers in 30- or 40-years doing things in one particular way, and they don't see a need for change."- R2

R2 affirms that reluctance to change has something to do with age and also, due to the newness of the method and fear of change as noted by R9. The younger workers seem to be more tolerant with new technologies.

"I'm not quite sure why but I know in my 45 or so years in the industry, for about 40 of those, the industry seemed very reluctant to change, yeah, but I do sense there is an appetite for change in recent and I think the industry can now see what offsite could offer- less wasteful solution that involves fewer people."- R2

"Yeah, I would say... I would say it's probably 2-fold, it's. On the one hand, it's quite new, so offsite would be different to what people are doing traditionally,

so it's not the way people work at the moment, and typically people are scared of change." - R9

A good number of experienced industry players are found to have strong preference for the use traditionally method of construction than new methodologies. This is another serious reason wider adoption seem somewhat difficult.

"I think that you know they you can't just change." - R12

"So, I would say I would say across the board, there's a dependence on, and current reliance on the traditional methods." - R9

There are also a number of worries surrounding the adoption of OSC, creating a fear of protectionism. The fear resolves around loss of job due to automation,

"Ah, yeah, yeah, it's interesting so a lot, yeah, so people might think that if you automate things more that people will lose jobs and because there's less manual work to do" - R11

And continuity of projects due to insolvency

"I think another factor is that individual offsite solution providers offer something that's quite similar, but not exactly the same from a client's perspective. I think their fear could be that if I embark on this project with a single provider and they go burst or they become insolvent, it can't change to another solution provider halfway through." - R2

and commitment to investing in OSC production owing to change in government and its policies amidst other fears.

"So, you know a government comes into power, and then in power for five years in the UK until the next election. For a lot of them, particularly investors, companies who want to invest in offsite technology, the one thing they want is certainty. And certainty for an offsite manufacturer is longer than five years. Well, they don't want to do it."

Cost: The cost of executing construction projects using OSC has been in the forefront of debate regarding the wider adoption of OSC (W. Pan & Sidwell, 2011). There has been varying opinions on cost with respect to OSC adoption (Sutrisna, Cooper-Cooke, et al., 2018b). This study observed 5 building blocks to OSC cost influencing factor. They are Capital cost, Cost saving, Cost control, Initial setting up cost and Cost certainty.

The cost of OSC projects has been debated to be more than a similar tradition project (N. Blismas & Wakefield, 2009). This opinion, as held by many, is one of the leading factors for the slow adoption of OSC (X. Zhai et al., 2014). Historically, cost has always been a determinant factor is construction projects and not just on OSC projects.

"With a lot of factors, however, cost is almost always more significant, more important in that discussion than many of the other factors. It has historically been, and now we'll still be, but for I mean maybe for other reasons, which is what we're trying to hit "- R9

While cost is an issue in construction works, OSC capital cost is misunderstood by people and misinterpreted by cost consultants (W. Pan & Sidwell, 2011). What has not been put into consideration by contractors and investors is the long-term assessment of OSC cost.

"I think clients are still concerned about cost. It's not necessarily a lower capital costs, and sometimes I think we find that people misunderstand what the capital costs will be. Certainly, sometimes cost consulting too long with the issues of how you can make savings or tree limbs and so on. So, cost can be seen to be an issue. It isn't necessarily in particular. You look in the long term. But it can seem to be an issue"- R3

R4 hold the opinion that cost/m² is higher in OSC when compared with traditional construction.

"There is a blocker, that's if you like. Per square meter offsite construction is still kind of, on average, more expensive than traditional, and there was a report published by BRE, I think it was last autumn, which was looking specifically at housing and a figure that came to mind there is that. Offsite construction is still far more, for housing is still about £3000 per square meter, whereas traditional construction I think as a median value of about £1800 square meter that goes down to about 1200 for your cheapest sort of volume houses. But it can also go up to three and a half thousand for sort of bespoke executive house. So, first thing is cost it."- R4

While there has been a broader view that OSC capital cost is high, studies have also shown that OSC has so many long-term cost saving opportunities if employed in a project rightly. The use

of less labour, shortened on-site time, speed of project execution, lead time saved, less consumption of resources and energy all account for a lot of cost savings unlike in a traditional building.

"All that costs money. And if you build a site 12 weeks quicker, these things are rented quite often in this space, so if you're not using that space for 12 weeks, all these savings should be lumped into the overall assessment, but they don't look at that"- R7

R5 attest that time saving, cost and resources is one of the missions of the government in advocating for the use of OSC.

First of all, Construction 2025 paper which was published in 2013, and this is a government publication. Uhm, and that was promised, well, that had an aspiration that through use of sort of offsite approaches we want to kind of reduce the cost of construction by 50% by 30%, reduced schedule by 50%, improve export opportunities and improve sustainability"- R5

Another major advantage that has been established on cost influencing factor of OSC is cost certainty. The fact that the project scope can be frozen early enough is a big plus for contractors and suppliers. This gives little or no room for variations and extensions which has been known to be major shortcomings of the industry (C. Egwim et al., 2022).

"People still perceive it as being more expensive; and what we're trying to get across to the industry is that you can better guarantee the cost because you've got more control over it through building in a factory environment."- R11

Initial cost as perceived by people attempting the use of OSC is from two views primarily- one is the initial setting up cost of production factory.

"So unless the industry is prepared to invest more in itself, so if the clients are prepared to spend more money with the industry. The industry is then prepared to invest more than we can grow, secure well run, actually, high tech factories that benefit the industry, but we're at the nursery stage at the moment and we can't expand because the finances hold us back on both sides."-R2

The second is the initial procurement deposit made, popularly called preliminary cost or mobilization cost. Both of these initial costs have been reported to be huge when compared with traditional construction.

"Maybe, all right, the factors that are inhibiting, uhm, are potentially costs.... Yeah, like upfront cost...and upfront capital costs in new manufacturing equipment"-R11

"If you look at the building when it's in operation and an end of use and so people need to look beyond the initial direct costs "-R11

Finally on cost influencing factor of OSC is cost certainty. The ability to freeze design early enough and determine the procurement path brings cost safety and certainty to the process. This positive addition is further aided by the factory production where other management principles such as production management and lean management adds credence to cost certainty.

"It's that you can better guarantee the cost because you've got more control over it through building in a factory environment"- R11

Health and Safety: With yearly accidental occurrence on construction site claiming hundreds of lives and leaving thousands mutated or injured to some degrees (Widaningsih et al., 2018), health and safety of workers has become a serious concern to the government of UK. The construction industry leaders also have garnered enormous efforts to ensure accidents rates on site is kept at a decline through different company policy, thus augmenting the government efforts. Despite the initiatives from government and industry executives, construction sites still account for some of the highest records of accidents and death annually unlike their manufacturing counterparts. Therefore OSC, which is the closest resemblance of the manufacturing sector is seen to be the probable way forward in addressing the large number of accidents and deaths associated with the construction industry. R1 noted that OSC reduces site incidents through reduced labour, precautions in moving large components and controlled factory operations.

"I do think working in a controlled environment factory environment is far safer than working on a on a traditional building site. I think there's far more potential for accidents on a traditional building site. I think when it comes to looking at moving large components, assemblies, and objects that I think the precautions are in place. Perhaps risks of moving something which we, I don't know.... But I think you, you're reducing the number of people on the traditional building site. The labour force is much less much reduced if you reduce the

human interaction, then you're likely to reduce the accident frequency rate anyway automatically"- R1

R7 also noted that a major benefit OSC brings to the construction industry is health and safety.

"OK. One of the things we've got in offsite construction, the benefits are very much health and safety"- R7

Work-life balance of construction workers would be assumed to probably improve with the adoption of OSC, but R4 submitted that OSC does not necessarily bring the assumed well-being despite some reduction in construction associated risks.

"Offsite has always kind of had these benefits. That's because you're moving a lot of work away from the site into factories, as we've kind of said before, it provides a better work, though the presumption is there's a better, you know it's better to work in a factory rather than a construction site. It's warm, it's clean. The shift-your hours of shifts, you know are kind of a little bit more secure. You don't have to travel miles to site every day and then travel miles back every day so from workers point of view, I think it it's a kind of win situation that if you could still be working but doing it somewhere local to your home and not kind of traveling because you reduce the number of people on site, I think that's probably one of the first major benefits of offsite that we've kind of said before."-R4

Work-life and balance may not necessarily be improved by OSC contrary to what one may assume as noted by R9. He posited that being able to work more safely or in a safer environment

does not imply reduced work hours or having more time for other activities that could enhance well-being. The best OSC brings in this regard would be efficiency and productivity at work.

"You know they're still going to be able...they're still going to have to work the same hours of the day, it just means that more is being done with that day. So, it's possibly less time on one project, but ultimately in terms of work life balance, I don't think it would... I, I don't... I don't see how that offsite will change the way people work. It's kind of makes sense. It makes their life less risky...I mean building buildings and safer but, it doesn't mean they'll have more time to do other things."-R9

This study therefore deduced that OSC does not really contribute significantly to Work-life balance though it brings about some form of improvement to safety and how work is conducted.

Decision to use OSC or not: Decision has been a powerful element in the execution of any proposal. The decision to adopt OSC is down to the parties involved amidst some other factors or metrics. R1 noted that the individuals need to make up their mind as to what to build and how to go about it.

"...I don't think there's anything that you can do to ensure that actually happens. I think it's down to the individuals concerned. And they have to make up their own mind...they make their own decisions, make up their own mind as to how they actually want to build something."- R1

There is the need to ascertain which methodology would best suit the intended project and not making an afterthought decision mid-way into the project as this has been found not to deliver the best benefits of OSC.

"It's just what you're likely to flag up for...it is going to be different if you go down one path then the other path. I think it's just whether you actually go down that route. What's is much trickier is if you get to a certain level of design development, and then you start thinking, actually do I want to go to offsite? Then it becomes trickier to move-switch over."-R6

"OK, so most people that use offsite is an afterthought, so they don't plan it before any at the start of the project, and so they decide to go to the thought of using offsite halfway into the project. And so, if they want this solution, it is that they should think about it from the beginning of the project"-R5

R9 therefore advised that making decisions early on whether to use OSC on project would deliver the best results and benefits of OSC, including addressing planning hic-ups.

"If you utilize offsite methodologies, you have to bring the decision-making process a lot sooner or a lot earlier on in the project. And so, if it's earlier on in the project occasions on planning application that you're making, if they have to be decisions that are made pre-planning, that means that you know once you get to planning"- R9

Some other important elements that influence decision on projects are client, stakeholder engagement and participation, project goal and communication.

Clients have always been about the most important factor when it comes to the direction a project faces or the eventually outcome of it. On the decision to use OSC on a project, R8 noted that on past projects, the clients influenced the decision. R2 also observed that the decision to use OSC on a project is largely influenced by client and project type.

"OK, well I guess for me so I'm further down the full chain when it comes to procuring. So, I'd say the person who more influences it is my client."-R8

"So, I think the answer to your question if it's not too vague, is it depends on what you're building and where you're building and who the client is."- R2

The success of any project is a function of how well the stakeholders collaborate in realizing the project objective. A barrier that is influencing the wider adoption of OSC is the relevance of the present contractual document and how the stakeholders engage with it. While the present construction contract agreement may not have well accommodated OSC approach in its details, a hurdle for the construction industry stakeholder to cross is how to collaborate despite this deficiency.

"What I'm not so certain about is whether the contracts that we work under are yet adaptable enough to offsite solutions, and some of the barriers that the contractual arrangements bring are how can we work together and collaborate together at these very early stages?"-R2

Early engagement of team members and good collaboration among them is what can help access maximum benefits of OSC such as waste reduction, cost saving, timely delivery.

"Similarly, you know the cost consultant needs to think how this project will be of lesser duration. Will the overheads on the project be less? Will there be less waste? So I think the industry is recognizing that to collaborate better and engage at an early stage is the really major way to make an offsite solution work." - R2

R3 buttressed the above view by citing a project instance where early engagement of a team member and good collaboration yielded a positive and desired outcome despite the shortcoming noted by R2.

"The manufacturer was brought in a very early stage. We were able to work very closely with them and got some really good outcomes from it. We could not have designed it, and then thought, I know, let us do it using a volumetric system. It would not have worked. We had to do it hand in hand with the manufacturer to make it work and get the best outcome."- R3

What a project is set out to achieve is another possible influencing factor that defines what construction methodology would be adopted. Where delivery time is constrained and project is required to be delivered within a specified period or where quick delivery to meet up with a deadline is the target, OSC could come in handy. Other situations that may bring about the use of OSC. R4 and R1 noted that the goal, objective, value, system and mission of a project largely dictates the methodology that would be best suited.

"I don't think that you should ever go into a project, say, right, I want to do this building, I want to do this housing development, and I want to do it offsite. I do

not think that is the right decision to make at the start. I think when you want to plan any project, you have to think about what is driving the project. What are your objectives, what are your outcomes? What are your values? And then use that to drive how you want to kind of deliver it."- R4

"I think the major factors that influence things are the suitability of the actual system for what you're actually trying to build. But I think what I always say to people about offsite in general is it is really possible it is not suitable. So, you look at what your client wants, what they want- the end result of you are trying to achieve, and you try to then pick the very best delivery method."- R1

Communication among project stakeholders play a critical role in the success of the project. Each project team member has its focus on a project but construction project, like many other projects is inter-dependent. Therefore, synergy is required among the different team members and what can bring about the required synergy is adequate and clear communication. R4 noted that for reasons such as divergent focus, ego or personalities, teams' members do not communicate or relate well, and this impedes on project success.

"So, these are all kind of organizations with slightly different focuses and sometimes they don't sort of communicate, come to each other very well which kind of leads to the criticism and the kind of fragmentation of the industry; wherever that stands, personalities or not, I don't know."- R4

While traditional method of construction is improving in delivery due to adoption of modern-day technology, the methodology still does not fulfil the global yearning for improved work process and delivery. OSC is being thought of as a satisfaction to this longing because of its perceived advantages over traditional method in terms of time saving and increased speed of onsite construction, improved production process, waste reduction, standardization, ability to better infuse digital technology, better coordinated force and ability to avert adverse weather condition. For instance, R9 and R12 noted that in some of the OSC projects they have executed, time saving was a major factor that OSC brought to the projects.

"Also, I think that the saving time taken factor is ultimately, I think, the biggest win." - R9

"I know one of the projects we did, which is, uh, the Grand Hospital in Wales and part of it was to save about 233,000 hours by introducing offsite construction components"- R12

In another instance, R2 reported that speed and brilliance of assembling a house in a short period of time is a huge advantage when compared with his years of practise in delivering houses. R9 attest to this in another project where twin 25- storey structure was delivered quickly without using any external scaffold.

"I think the answer is probably dependent on which sector of the market you're in. So, for example, one of the examples I suppose it benefits in offsite is this speed of delivering, brilliant speed of assembly. I mean, yes, I have worked a

long time in the house building industry and potentially the ability to erect a house in a day is the major driver for homes builder"-R2

"So, I think a big a big factor was the speed of construction that they wanted to make the building weathertight. And also, because they wanted to be able to build the two towers- those two towers with twenty-five stories without any external scaffolding."-R9

A responder earlier noted that one of the reasons why prefabricated building failed earlier was that it arrived before its time-there was no adequate technology that could enhance its use. R4 shares a similar opinion that unavailable matured technology to knit OSC together is a reason why it failed in its earlier usage and that for it to work better in this age, a good technology with good assurance model must drive it. Today, a major advantage that OSC seem to have been its adaptability to modern technology better than traditional method. R11 noted that OSC adopts digitized and better efficient approach than traditional method. This has helped it deliver buildings with better pre-manufactured values.

"I think probably offsite construction failed in the 20th century because we didn't have a mature kind of digital technology to kind of knit it together. It is my own sort of personal opinion.... To do offsite well, you need a sort of good digital tag behind you, and you also need a good assurance model as well"- R4

"It (OSC) is adopting a more digitized and more efficient approach and increasing the premanufactured value of the buildings that we deliver"- R11

The world, on a daily basis, is seeking better ways of getting things done. Many sectors of the economy are constantly improving their work process and achieving better output while contributing positively to global climate change through improved process. OSC offers the construction industry improved construction process with potentials to reduce negative contribution to climate change. R12 noted that the factory approach to construction better applies to OSC and negates unwanted resource consumption and wastage using lean approach. R11 stresses further that using OSC would most likely eradicate idle site equipment (which are sometimes eventually abandoned on site and left to rot away) and optimize production tools and hours as a factory can be equipped to work all day.

“Also, lean process in terms of, you know, just manufacturing what you need as against taking so many things to say and then having to also demobilized from site and bringing materials in, so it (OSC) does help investing process and gives a lean process for construction.”- R12

"You've got idle equipment that's sitting on site that's not being used all the time, but a factory can operate 24 hours a day if you if you need it to, and if you've got the systems in place to do that"- R11

The improved process has largely been found to result in improved material production. The improved materials provide better premanufactured value, durability, eco-friendly, improved thermal performance and improved fire-rating without necessarily adding to product weight or width. Another advantage to this is that human errors can be better avoided.

"So fundamentally, I think most of those issues you talked about would probably be better solved through factory construction...People do things that you don't expect, and I hope the processes in the factory would stop those individuals"- R2

"...and people are realizing that through building in a in a factory environment, you've got a greater level of quality control. You can use machines and equipment to install things like insulation, and you can better guarantee that the building is going to meet their performance requirement"- R11

R1 further noted that building in factories produces better tolerance for installation and assemblage with materials consuming less energy while R12 opined that a better coordinated workforce is achieved through building in a factory.

"Operationally, functionally, it should actually be far more efficient because, as I said before on tolerances, the building tolerances are far better. It is probably, I am aware of a residential project in Mitcham in London... no water supply was required on site...and the flats the Stafford Flats are operating at something like 20% of the energy consumption of a standard traditional build."-R1

"So regardless of weather conditions, or you know what restrictions, there you can bring people under one warehouse and achieve results"-R12

The construction industry has been associated with enormous amount of waste worldwide. Millions of tons in waste are generated from construction site annually. OSC has been adjudged to be a construction methodology that greatly reduce waste generated. Aside reducing waste generated, OSC can recycle the waste into useful material and also re-use offcuts.

"Uhm, it's easier to recycle materials if you're actually working in offsite in a factory. I think that the figures for actual traditional construction waste on residential projects is quite frightening. I think it's something like 3 skips per house. I'm going to say if you take that into a factory, you probably reduce that by 70% if not more. And it is far easier than to recycle any waste materials or unused material, shall we say uh, because they're not really wasted. They really need to be recycled and reused."- R1

"We also in traditional construction methods are extremely wasteful. And in my lifetime, there have been numerous reports that suggest that as an industry waste between 20 and 30% of the materials we procure...Yes, some even say 40%.... Indeed, who knows what the real figures are, but of course waste does not only occur in material losses, it is in rework and inefficiency and processes and all that sort of thing"- R2

One of the reasons for request for extension of time (EOT) leading to delay or prolonged construction duration is inclement weather. Traditional construction method is usually hampered by rainfall or other forms of force majeure. With OSC, most external related blockers could be avoided, and construction projects executed as scheduled.

"So regardless of weather conditions, or you know what restrictions, there you can bring people under one warehouse and achieve results"- R12

"If we think about the way our industry has to operate on construction sites, it's a very hostile environment in terms of weather in terms of traffic movement in terms of heavy materials having to be moved in terms of complex structures having to be delivered."- R2

Sustainability: Sustainability is one of the major objectives of the World Economic Forum and is also among the foremost millennial development goals (Mollaoglu-Korkmaz et al., 2013). Sustainability is playing a crucial role in recovering earth's 'wellness' due to climate change impacts. The traditional construction approach has massively contributed to climate change impacts due to waste generation, large amount of embodied carbon consumed and excessive release of carbon as by product of activities. OSC, through factory production and use of improved production process, can help drive the Net-Zero Carbon emission, building whole life cycle, energy efficiency and consequently environmental impact if fully adopted.

The construction industry has been associated with lots of carbon generation during the building life cycle. Owing to difficulty in properly managing the end of life of many buildings, a negative environmental impact has been observed. Many of these buildings are demolished at the end of life with very less parts of the building being recovered re-used. The traditional method of construction uses permanent binding agents like cements to keep parts together, making it difficult to separate them when the building life ends. Therefore, the embodied carbon of a building in its lifecycle, as noted by R11, should be given a significant consideration.

"It should really be that embodied carbon should really be at the forefront or whole life carbon even as well because we cannot continue to build and demolish buildings the way that we're doing now."-R11

The OSC methodology has potentials to reduce the embodied carbon and improve its life cycle and allows for reusability of larger number of materials.

It is no longer news that the entire globe is warming at an increasing rate, and urgent measures need to come into place to salvage the deteriorating situation. The net-zero plan has been proposed by first world countries and is being pursued by almost the entire nations of the earth (Swarup et al., 2011). The construction industry is noted by R10 as a major contributor to the global warming issues. R10 further stresses the need for the construction industry to change to save the ecosystem. The concept of OSC is such that help actualize this mission as R11 further noted that meeting the New-zero target is an important driving force in adopting OSC as method of construction.

"...we are in a climate crisis and the built environment is one of the worst guilty parties contributing to climate change. So, 40% of all emissions are down to buildings and the built environment. So, we need to change. We need to look at what we are doing and rethink what we're doing."- R10

"Yeah, but actually the most important driving force is meeting the Net-Zero emissions targets."-R11

Aside the high embodied carbon of traditional method of construction and inability of same method to enhance the mission of net-zero carbon emission target, the method has also been

known to contribute to environmental nuisances such as noise pollution generation, road closure, air pollution. R9 and R11 noted that fabricating the building in factories would *reduce environmental disruption aside shortening the time construction.*

"...also, fabrication because it means there's less, less disrupt less disruption on site, OK. You know less time creating less of noise pollution and damaging the community, and you know quicker delivery of buildings from design to construction. I think that is a major factor."-R9

"Like we are seeing more of that, they want to deliver these bigger projects more efficiently with less disruption to the surrounding area. So, we're seeing increased adoption in that area too."- R11

Owing to the materials used in traditional construction and the method of construction, the buildings are known to consume high energy. With rising environmental impact and climate change, world leaders are advocating for renewable energy usage rather than continuous consumption of fossil fuels. Though efforts are made with traditional construction building materials, the results show energy efficiency is still below desired level. R11 verified this point by noting that the energy performance level designed is not usually what is delivered on site.

"...buildings are designed to meet a certain energy performance level, but that is not what is always delivered on site, or there's no evidence to really demonstrate that."-R11

R3 noted that the UK government stated mandating some house providers to achieve some level of pre-manufactured values (PMV) for building materials.

"Yeah, the government is now mandating a certain level of PMV for homes England for example. Though, in some cases mandated, but more typically it's just looking to do things now to achieve better outcomes in terms of productivity and quality and so on."- R3

Therefore, there is need to look beyond the ways things are done now and investigate how to achieve better efficiency in terms of product outcome and quality. R1 submitted that there is a potential for improved in energy efficiency if construction take a step back from its large energy consumption and use and borrow a leaf from the manufacturing counterpart.

"So, there's this potential, and then if you if you sort of take a step back from the energy consumption and use."- R1

Sustainability is a global cry, and all hands need to be brought on deck to achieve it. Sustainability is a big factor OSC is bringing on board to the construction industry.

"Yeah, yeah, so quality is another one, and sustainability is a big thing as well with offsite construction"- R4

Doing things in a sustainable manner within the industry using OSC will not only add social values to the projects but also foster winning more contract government projects.

"...but in other words that you're not gonna stand a chance of winning central government contracts unless you procure for value- you include social value- you do things to sustainable manners, and I think the only final way to do that really is offsite, so that's it."- R7

Government and Regulations: The role government plays in the development of any nation cannot be underestimated. The government drives economy through policies, regulations, incentives and interventions (Jin et al., 2021). The construction industry is largely driven through these same avenues. The government drives the required quality delivery and building efficiency through planning and building regulations. Despite efforts by traditional builders to attain the increasing demands of efficiency, these demands are becoming harder to achieve using traditional method of construction due to changes required by the regulations.

"That the building regulations, particularly with regards to thermal performance, the building regulations are changing and has changed, and it's becoming a lot harder to achieve the requirements of building regulations using traditional construction."-R7

Studies have the opinion that planning regulation for OSC should not be entirely different from what it used to be originally with traditional construction, though it may need to be altered in some areas to accommodate the demands of OSC standards. Same applied for construction and contract documents.

"I don't think planning regulations should be very different for offsite, I mean compared with traditional. In terms of lines, the likelihood is that the building

or building footprint will be slightly larger. ...So, I think in terms of land there should be no difference whatsoever or very very very little difference in terms of planning."-R1

The UK government has been applauded in reports and extant research articles for her support, interventions, incentives and driving policies enacted to ensure wider adoption of OSC in infrastructure development. Such efforts include mandatory policies of executing a whole or a part of a project using OSC if UK government would award the contract to you.

"I think the major...I think one of the major milestones was this 2017 presumption in favour of OSC... So, in other words, what that means is, you know, if you want to come, if you want to be involved in building, you know in buildings that are procured by central government, you are going to stand a chance to win the bid if you propose offsite solutions"- R3

R7 submitted that the government has become the cheerleader of OSC through provision of legislations that results in stability of the concept. The respondent therefore implores the government to maintain this direction through relevant legislations.

"I think the government has come up... It's only place government coming basically with a presumption for offsite which is a good thing, which is an encouragement. I think, but this hasn't been backed up by perhaps and looking at the process and just looking at perhaps encouraging investment.... Perhaps more incentives certainly did for the investment into the actual manufacturing capability... But I think, politically, uhm, I'm in two minds about whether how

much intervention there should be some encouragement, but perhaps not any intervention." -R7

"And the government are becoming more and more champions of offsite construction. And where it becomes legislation, that's when people have no choice but to change. Uh, we need government to give us some stability- the direction needs to be maintained."- R7

Furthermore, the UK government is doing well in raising awareness about OSC through publications, webinars and training schools like the Supply Chain School and other means possible.

"The government are trying to raise awareness as well..."- R7

"Organizations like the supply chain school and others, you know, there's plenty of webinars and things right these days for us to look at... That, and indeed you know from publications so. I mentioned in the RIBA plan of work, DfMA Overlay, I think. It is really good material and now the government is pumping out reasonable amount of material on this, and it is quite useful..."-

R5

Some other measure the UK government has taken to ensure wider use of OSC are provisions of incentives and interventions.

"That's how it can happen. Yes, it is uh... if there is more government incentive and you know, yes direction, I think they could only help"-R2

However, the UK government have a significant role to play (beyond their present support) if OSC would gain wider adoption. Also, the respondents reported that some ministry within the UK government are already favouring OSC solutions in the execution of their projects.

"So, I think government has a really powerful role to play in setting the direction of travel in the industry and I'm aware that many of the several government departments are currently favouring offsite solutions such as, I think, Department of Education. I cannot remember what the others may be... Ministry, justice, but several government bodies are now favouring offsite solutions, which I think is great."- R2

Construction Industry Market: The forces driving the market play a critical role in how well OSC sits in the industry. Characterized by high fragmentation, complex nature, supply upon demand, funding, delays, reluctance to adopting emerging technologies and large number Small and Medium Scale (SME) businesses, (many of which are sole businesses), the industry is sceptical about what dynamics and disruptions the wider adoption of OSC may cause the market and consequently the economy.

The construction industry market has been described by many scholars as a complex, fragmented and volatile market. With the industry employing some of the highest labour forces and a major contributor to GDPs, the complexity of the industry cannot be doubted. Like other businesses, its investors are set out to maximise profit, even if it would be at the detriment of its consumers. The implication of this is that a developer adopts a construction methodology that best satisfy its business vision.

"...so, Theresa May report is, you know, the study of the housing market when she was Prime Minister. And yes, that was the headline... figure out the housing market is pretty much broken so, it does not offer the best solution for the customer, and it does not offer the best solution for the planet. But what it does do is offer the best solution for the developer, and you know that is where we are, I am afraid."- R10

Though the government has ensured mandatory, encouraging, and driving policies to stamp OSC in the construction industry and market, the industry players' knowledge of OSC business has not demonstrated ample mastery for profitability and wider adoption. The implication is failure and that would lead to discouragement in OSC adoption.

"...and of course, you also need people who have that knowledge- the knowledge of the market. Many people really want to go into offsite. They do not know what the offsite market looks like. And when they start failing, they say offsite is not good, offsite is not good because they do not have the knowledge- they do not know the offsite construction model"-R5

Another issue to note is that construction industry brings together large number of discipline and professionals and also relates with vast number of businesses. The inter-dependencies of the different stakeholders bring about much fragmentation of the industry which today is a leading challenge the industry is battling with (Ngoc Nguyen et al., 2020). OSC, with a factory approach, is hoped to close up the existing wide fragmentation and present a relative streamlined dependency for the industry.

"I think it was a good reason not to revert to the industry's norms, which used to be fragmented in its workforce, to be on very low margins to be building in a hostile climate..."-R2

"Well, I think it needs to be helped along by government because I think the industry- construction industry is probably too fragmented to do too much without some sort of oversight from government or through regulation."- R3

The interview responses suggested that there is a form of market readiness for OSC from the perspective of the industry professionals.

"The offsite construction is here and that is not going back. You know, I would always push for offsite construction in the future"- R12

"And somebody asked me the other day, what's different this time? I am not 100% sure what is

different, but everything is different."-R7

However, the market cannot ascertain the production capacity of factories to the components.

"There can be supply chain issues in terms of market availability, the capacity of the market to provide volumetric solutions. So I think we always have to be wary of that"- R3

The industry, in adopting OSC, needs some form of regulation to ensure seamless integration and procurement of the methodology into the market.

"Yeah, it's quite slow, I think. And the market itself is not particularly well regulated. So if you were in the market, when the business of trying to procure an offsite system, it is quite difficult to know."- R2

While many industry players are accustomed to the traditional construction market, it is not clear if they understand the OSC market dynamics nor if the existing model suites OSC fundamentals. For OSC to thrive in the construction industry, its business model needs to be adaptable to and well understood by the industry players.

"I think the UK has to find an alternative to his traditional methods. I am sure you will have read the Farmer review which, uhm, looks very seriously at some of the availability of labour and skilled personnel, for example, which with a transient population and how the Brexit has gone through. I think the availability of labour is reduced and I think it actually compromises the ability of the industry to deliver what it needs to deliver"- R2

Funding plays a critical role in the successful execution of construction projects. In an economy that is majorly property driven like UK's, the UK construction market is majorly funded through mortgage. A few people can make outright purchase of houses. Mortgage lenders have been observed to have reservations for funding OSC buildings. Following the Grenfell tower fire incidence, the mortgage lenders have been observed to have preference for traditionally built.

"Yeah, one of my experiences in housing for so many years is that mortgage companies and lenders generally like solid materials like bricks and blocks and concrete and I could see here maybe..."- R2

The insurance companies also have been observed to share similar opinion with the mortgage lenders.

"Insurance is a massive issue at the moment."- R10

R10 further lamented that both issues constitute major blockers to the wider adoption of OSC within the UK construction industry.

"...so definitely at the moment, trying to get insurance for modern methods of construction is so complicated, so difficult. And so, both construction insurance and then property insurance, ongoing property insurance. So, so there is a, you know a major problem there. Yes, there's optimism, but there is still quite a long way to go, so it is great that you are looking at this"- R10

SMEs have been identified as a major contributor to a nation's development (Shang et al., 2020). Its importance cannot be overemphasized in any thriving economy. The construction industry has a handful SME companies as sub-contractors. A major characteristic of SME is low capital and equipment aside being one-man business which can fold-up anytime. OSC is characterized by large initial capital set-up, and this may negatively impact the sectors which constitute the bulk of the industry and employees the most of its labour force. A wider adoption of OSC without adequate assessment of its implication and plan to accommodate construction SMEs may spell a fall for the industry.

Final one I want to mention on this is that offsite construction tends to be, especially at this sort of more, I would say kind of flash technology level. It tends to be something only frontier ones... whereas you know, over 90% of the UK's construction industry are self-employed. Either micro, you know one person builders or small. You know small medium enterprises. How on Earth is offsite relevant for them that? That is a big question I think needs to be answered. - R4

R4 further noted that:

"I would also say please think about the small medium enterprises in the micro build. Well, let us just always have a back, the thought in the back of your mind on how this can benefit them. OK. That would probably be my final word"- R4

OSC Knowledge: Extant literature submit that there is paucity of knowledge on OSC and its modus operandi (Gan, Chang, Zuo, et al., 2018). This is said to be one of the reasons hindering its wider adoption, especially by construction industry workers and manufacturers. The absence of abundant OSC knowledge could be traced down to academic-industry gaps (Nadim & Goulding, 2009). Some of the interviewees also share this view.

"A project organized by the construction Industry Training Board, recognizing that the actual skills and knowledge about offsite construction offsite manufacturing were quite limited..."-R1

R9 further noted that:

"Secondly, is the lack of education around how to utilize offsite and where best to utilize offsite."- R9

Further down the line on paucity of knowledge, there is an academic gap between the present academic curriculum and the actual practise of OSC. The reasons may be due to the perceived newness of the method.

".... there is a gap between what is lent in school and what is practiced."- R12

R12 continued:

"I think that modules dedicated to OSC...well, that the modules are just dedicated on the surface. I did a bit of offsite construction, but it was just on the surface understanding, just a type of delivery."- R12

There seems to be a long way to go in acquiring requisite knowledge that would increase the wider use of OSC.

"Probably a lack of knowledge generally across the industry, so we need to raise the knowledge across the whole construction sector, not just in architecture and what. It needs to be done early. Early design stages, because if you leave it too late, you lose the benefit, you lose the opportunity to maximize the benefits from it. So, I think we need to improve awareness and understanding and what it means to follow a DfMA process" – R3

"I think there's still a lot to be learned and still." -R12

The academic institutions are bracing up to ensure to students in construction related academic pursuits do not leave the institutions without some form of knowledge about the changing dynamics in the construction industry.

"Also of course, training is important and the good is that training is currently going on now, so some colleges now are delivering modern method of construction in their college."- R5

However, a better portion of the knowledge to be acquired are mostly available not at the undergraduate levels. The gaps that exist could not be adequately catered for through higher education only. Further education and trainings have been the channel through which the knowledge of OSC has been diffused to the manufacturers and industry workers.

"I'm sort of aware there are one or two courses around that are focusing on this, but they tend to be post graduate or in further education rather than in higher education"- R3

"So, at the architectural school level, I really think it's not being taken seriously enough yet. But I do want to refer back to the RIBA plan of work overlay to give them credit for that. But the other level I am currently today, and what I have been doing before I spoke to you today, is putting together a proposal for some offsite education. If you like, in things like colleges, so, these are young school leavers [can acquire OSC knowledge] ..."- R2

Therefore, in order to address this issue, there should be early diffusion about OSC and its applicability through documentation of projects.

"Probably a lack of knowledge generally across the industry, so we need to raise the knowledge across the whole construction sector, not just in architecture and what. It needs to be done early. Early design stages, because if you leave it too late, you lose the benefit, you lose the opportunity to maximize the benefits from it. So, I think we need to improve awareness and understanding and what it means to follow a DfMA process"- R3

Another challenge to the available knowledge on OSC is the absence of relevant OSC project data (Steinhardt & Manley, 2016). While on this research, the study attempted to find out if there exist any dedicated OSC project data for UK but could not find any except a list of OSC manufacturing companies by Kier. Some notable housing organizations and research institute were contacted but they could make available the required information. Some interviewees seem to have encountered similar barrier to OSC adoption.

"...on number of OSC project data, I don't think anybody has thought about that information, but I think what you find is that anything which where there is repetition or the potential for repetition, then the offsite construction"-R1

"Indeed, who knows what the real figures are, ..."-R2

This area would be an interesting research area to consider going forward on this project OSC. It is worthy to note also that OSC project database is the only area in this study that do find a

match when the qualitative outcomes were compared with the Systematic Literature Review (SLR) outcome.

An aspect of OSC that most interviewees touched on without being questioned on is the supply chain and logistics. That gives a pointer on the importance of the segment of project execution.

Since OSC involves part (panellist) of full (volumetric) size of component delivery, the logistics of delivery for seamless assemblage becomes more crucial. The supply chain has been a critical path in the successful delivery of construction projects. It manages the movement of product from manufacturing points to site delivery and assemblage.

One of the challenges of the supply chain is the planning the production capability of the manufacturing company and how the products would be delivered.

The traditional construction method has not been able to address this challenge maximally. But since OSC comes in a ‘pre-product’ form, the technicalities involved in its supply chain management is hoped to make the chain more seamless.

"So it can sometimes be really difficult to plan too far ahead on a site in terms of which houses you're going to deliver in which sequence, and I think with an offsite solution and the limitations of the factory that can be a barrier sometimes too"- R2

OSC is observed to have the most beneficial social value to the host production factory unlike traditional construction where labour can be pulled from different locations to different sites.

"There's a couple of things here because it can have a detriment on social value if all of your manufacturing is done, say in one part of the country and your project is in the opposite end of the country. You are not going to benefit the local community there in that case."- R3

A major factor contributing to construction project success is the procurement route explored. Most industry players, overtime, are accustomed to the traditional procurement processes. A strong relationship channel has been established over time. With OSC methodology model not in full synergy with the traditional method yet, effective procurement appears to be challenging.

"...you know they have a way of working which works for them. They have, you know they can build on experience from that. What plays into that is the procurement of materials and everything to do with a project that you know they'll have procurement pipelines already with suppliers and manufacturers and they'll have, uh, a large number of resources which they just go to, and it's known to them."- R9

Transportation of products is an integral part of supply chain logistics (Y. Zhai et al., 2018a). Volumetric modules and long length panels appears not to be in consonance with existing transportation regulations (V. Singh et al., 2023).

"I think that you know another main thing that might be a challenge might be transportations."- R12

To effectively move OSC modules from factories to sites, there may be needed to standardized modules to particular sizes or adjust the present dimensions of delivery trucks to fit module

ratio. In an extreme case, special delivery vehicles would be required to transport modules as seen in the construction of Burj Arab, Dubai. What option is adjusted better must also put into consideration the module weight and the road width.

"I think the predominant thing that comes to the standardized modular sections is usually the transport. So, the vehicle that transports them is over certain given size and there is a certain weight limit to how much you can put on a wagon on a road legally. So usually, the dimensional size in terms of design of a modular unit which usually would be a similar across..." - R6

In proffering standardization as a probable way forward in adopting OSC modules, the shape, size and environment of delivery site should be considered as well.

"Yes, so standardized exercises will always depend on the overall property size which will often be dictated by the plot of land size. But I think with the UK, being such an already developed country, the one thing that you can't necessarily prescribe is the shape and size of where you are building, so I think that does make it difficult to completely standardize everything."-R5

The shape and size of a land could influence the type of building that can be accommodated on it. This instance is a potential threat to the use of OSC which comes in a fixed size. Vehicular manoeuvrings, storage and hedging would be difficult in a built-up area.

"Even the site is a constraint and the type of project you want to put on it will definitely define the kind of challenges you will face. - R3

"So, for example, the logistics of volumetric modular might mean it's completely unsuitable in some sites with limited access, or but we all know the reasons"-R2

R6 added that:

"When it when it comes to standardizing something, I think the trouble with the UK in particular is, you're offering something in a piece of land that has had several buildings around it or near it."- R6

Overall, the supply and logistics should provide a reasonable level of secured pipeline for the project and protect the interest of project investors.

"...what else is inhibiting it? Not having a secure pipeline of work. So, if we want to invest more money in doing things using a greater level of digitization and automation, we need a secure pipeline of work and that needs to go 10 years plus, we need to have that, we need to know that we're going to have a certain amount of housing to build offsite"- R12

"So, because you need to have the supply chain, you need to get them, but you need to make commitment to them. So that comes down to the procurement process and that needs to be right. And so, so those are the issues that need to be clearly addressed, or the process will fail"- R5

Table 9: Summary of Thematic Analysis Findings from the Interview

S/No	Underlying Issues identified from themes	Count	Themes
1	Low awareness, Professional awareness, Existing awareness, Awareness level, Awareness and adoption lies among majority stakeholders, increasing awareness, Recreating awareness, Awareness not adoption.	8	Awareness
2	Reluctance to change, Quality perception, Attitudinal perception, Monotonous perception, Cost perception, Dependence on Traditional Method (conservatism), Resistance, Fear of unknown (protectionism),	8	Perception and Attitude
3	Design issues, Repeatability, Building Style and Type, Bespoke buildings, Structural stability, connection issues, Inflexible nature of OSC, Better tolerance for poor quality	8	OSC Buildability
4	Digitalization/tech accommodation, Improved production process, Standardization, waste reduction, improved performance, coordinated work force,	6	Productivity
5	Time Saving, Speed, Ability to avert harsh weather condition.	3	Timesaving
6	Decision Making, Early Decision, client, Stakeholder engagement and participation, Project goals, Communications	7	Stakeholder Influence

S/No	Underlying Issues identified from themes	Count	Themes
7	Construction market, Fragmented nature of the construction industry, Market readiness, OSC Business/construction model, Need for OSC adoption and readiness to promote it, funding and insurance, Accommodating OSC in construction SMEs	7	Construction Industry Enterprise
8	Whole life cycle, Net Zero Emission, Embodied carbon, Environmental Impact, Sustainability, Energy Efficiency	6	Environmental Sustainability
9	Secure pipeline of work, supply chain, Transportation, Production / manufacturing (policies, capabilities and locations), Site/change challenges, procurement pipeline,	6	Supply Chain and Logistics
10	capital cost, cost saving, cost control, initial setting up cost, cost certainty	5	Cost
11	Academic Industry gap, improved educational curriculum to accommodate modern method of construction, Training, Unavailable OSC project Data, Paucity of OSC knowledge	5	OSC Knowledge
12	Quality improvement, controlled production environs, Quality control	3	Quality Performance
13	Planning Regulations, Govt driving policies and incentives, Govt interventions	3	Government Policy and Interventions
14	Work-Life Balance, safety	2	Health and Safety

APPENDIX 9: Survey Questionnaire (<https://forms.office.com/e/JuzpvkkL7f>)

RESEARCH QUESTIONNAIRE FOR FACTORS INFLUENCING WIDER ADOPTION OF OFFSITE CONSTRUCTION (OSC) WITHIN THE UNITED KINGDOM (UK) CONSTRUCTION INDUSTRY.

Dear Responder,

You are cordially invited to participate in an online survey questionnaire as part of a PhD research study conducted by Wusu, E. Godoyon, a Business Analytics Research student at Hertfordshire Business School, University of Hertfordshire, UK.

Before making your decision to participate, we kindly request that you carefully review the following information. Should you have any questions or require further clarification, please do not hesitate to ask.

You are eligible to partake in this study if you have direct or indirect involvement with the UK construction industry or are engaged in teaching or studying construction-related courses.

This study has received approval from the University of Hertfordshire Social Sciences, Arts, and Humanities Ethics Committee with Delegated Authority (SSAH ECDA) with the Protocol Number BUS/PGR/UH/05327.

The research questionnaire is designed to assess the level of Offsite Construction (OSC) adoption within the UK construction industry and to gather insights on how further OSC adoption could be enhanced. We sincerely request your valuable time and input in completing this questionnaire.

INTRODUCTION

The construction industry is undergoing a notable shift towards sustainable practices and quicker building methods. Offsite Construction (OSC), a growing prefabrication approach where building components are manufactured offsite and then assembled on-site, holds promise for addressing industry challenges. While OSC is gaining traction in Europe, America and Asia, its adoption in the UK remains relatively low, despite being considered one of the earliest adopters of the construction methodology.

To enhance the acceptance of OSC, various terms like Industrialized Building System, Modern Method of Construction, Pod Construction and Modular Construction have been used to rebrand it and make it more appealing. However, OSC still lacks widespread recognition as a viable alternative to traditional construction.

OSC Doctoral Thesis

This research seeks to uncover why OSC has not gained significant adoption in the UK despite its well-documented benefits. Through this questionnaire, we aim to identify the most critical factors influencing OSC adoption in the UK construction industry.

Your responses will greatly contribute to this investigation, enhancing our understanding of OSC and its potential in the construction industry.

Thank you for your participation.

Wusu Godoyon,

Doctoral Researcher,

Big Data Technologies and Innovations Lab

Hertfordshire Business School,

University of Hertfordshire, Hatfield.

070516188946

g.e.wusu@herts.ac.uk

CONSENT

Having considered the invitation for the survey, you will be asked to complete an online questionnaire. This survey/questionnaire asks about Offsite Construction in the UK, and it will take you approximately 15-25 minutes to complete and it may be less.

It is up to you to decide whether or not to take part. You are free to withdraw from the study at any time and without giving a reason. If you choose not to take part, you do not need to do anything further.

We hope that your participation in the study may well improve our environment for better living. Participating in the survey would give you room to test the developed Machine Learning Algorithm for any proposed building/construction project.

There are no expected risks for participants. Any data that you provide will be treated as confidential and the questionnaire is anonymous.

This study has been approved by the University of Hertfordshire Social Sciences, Arts and Humanities, Ethics Committee with Delegated Authority (SSAH ECDA). The Ethics Protocol number for this study is BUS/PGR/UH/05327.

If you would like to receive more information and for any other queries about this project you can contact me by email (g.e.wusu@herts.ac.uk) or my Supervisor, Prof. Hafiz Alaka (h.alaka@herts.ac.uk)

WHILE YOU HAVE BEEN IMploRED TO KINDLY FILL OUT THE QUESTIONNAIRE TO AID THE EXPLORATION OF OSC ADOPTION WITHIN THE UK CONSTRUCTION INDUSTRY, THE DECISION TO CONTINUE IS VOLUNTARY. IF FOR ANY REASON(S) YOU ARE NOT COMFORTABLE DOING SO, YOU MAY KINDLY DECLINE THE REQUEST AND CLOSE THE SURVEY.

A. PRE-REQUISITES:

NOTE:

IN ANSWERING THIS QUESTION, YOU CAN CONSIDER A PAST PROJECT OR AN ON-GOING PROJECT, EITHER AT THE DESIGN OR CONSTRUCTION STAGE.

IF YOU ARE HAPPY TO ADD ANOTHER PROJECT, YOU CAN DO SO AT THE END OF THE QUESTIONS ON THE PROJECT YOU HAVE CHOSEN HERE.

ALL QUESTIONS IN THIS SECTION OF THE QUESTIONNAIRE ARE COMPULSORY IN ORDER TO PROGRESS.

1. Have you ever worked on or been involved in any project(s) in the UK where Offsite Construction (OSC) was/is used for the project, or where a part of the project(s) was/is OSC?

Yes No

2. (If NO), Has OSC ever been considered on any of the projects you have been involved in within the UK?

Yes No

If No, then the potential respondent cannot go further on the questionnaire. If Yes, they may proceed to the following questions.

3. (If YES), Was OSC eventually used for the project?

Yes No

B. GENERAL INFORMATION:

(4) Specialization (If not a construction professional, please tick others):

Architect

Contractor

Interior Designer

Academic

Civil/Structural Engineer

Mechanical Engineer

OSC Doctoral Thesis

Electrical Engineer

Quantity Surveyor

Town/Urban Planner

Project Manager

OSC Manufacturer

OSC Marketer

End-user (Investor, occupier, house owner)

Chartered Professional

Others (State it)

(5) Highest Qualification ((If no formal educational at all, please tick N/A)

GSCE

NVQ

SVQ

OND

HND

Bachelors

Masters

PhD

N/A

Others (State it)

(6) How many years have you been in construction related practice?

Less than 1 year

1-5 year(s)

6-10 years

11-15 years

16-20 years

Over 20 years

7. How many years of your construction(related) practice involved the design or/and construction of OSC projects?

1-5 year(s)

6-10 years

11-15 years

16-20 years

Over 20 years

8. How many OSC projects have you worked on, including any current ones?

1-2

3-5

6-10

Over 10

C. PROJECT DETAIL

KEYNOTE:

TO ANSWER THE FOLLOWING QUESTIONS, PLEASE CONSIDER ONLY ONE OF THE OSC PROJECTS YOU HAVE BEEN INVOLVED IN OR CURRENTLY INVOLVED IN. HOWEVER, IF YOU HAVE BEEN INVOLVED IN MULTIPLE OSC PROJECTS, YOU CAN PLEASE COMPLETE THE QUESTIONNAIRE MULTIPLE TIMES, CONSIDERING A SINGLE SEPARATE PROJECT IN EACH CASE OF COMPLETING THE QUESTIONNAIRE.

THE PROJECT DOES NOT HAVE TO BE (FULL) VOLUMETRIC PROJECT.

9. Location of selected project:

England

Scotland

Northern Ireland

Wales

Isle of Man

10. What type of OSC concept was majorly employed for the project under consideration?

Volumetric (Pre-manufactured 3D primary structural system -volumetric units of entire structure or pods)

Panels (Pre-manufactured 2D primary structural systems)

Components (Pre-manufactured components- beams, columns, wall structures or slabs that are not part of a systemised design)

Pods (Pre-manufactured non-structural assemblies and sub-assembly components like slab cassettes and roof cassettes, etc)

Traditional building process improvements (large format walling or roofing)

Others

State it (them)

11. What class of building/infrastructure was developed for the project?

12. Residential:

Mass Housing

Private

Bespoke

13. Multi-storey:

Low-rise (3-7 floors)

Medium rise (8-15)

High rise (16-30)

Skyscraper (Above 30 floors)

14. Institutional:

Commercial

Educational

Recreational

Office

Others: State it (them)

15. What is the size of your site?

Less than 1 plot

1-3 plot(s)

4-6 plots

7-12 plots

Above 12 plots.

16. What client type owned the OSC project?

Private individual client

Private corporate client

Public sector client

Others

17. What was/is the OSC project duration?

- 1-6 month(s)
- 7-12 months
- 13-18 months
- 19-24 months
- 25 months and more

18. How long did the entire project duration take?

- 1-6 month(s)
- 7-12 months
- 13-18 months
- 19-24 months
- 25 months and more

19. How long would it have taken the project if OSC was not considered or used?

- 1-2 year(s)
- 3-4 years
- 5-6 years
- 7-8 years
- 9-10 years

20. (DV) What percentage of the project under consideration was OSC? You may use an approximate figure where you cannot provide exact figures.

- 1% - 20% (1) 21% - 40% (2) 41% - 60% (3) 61% - 80% (4) 81% - 100% (5)

Definition of terms:

Client-related Stakeholders: A group of decision-makers on the project. They include financiers, project managers, lead consultant(s) etc.

Professional Stakeholders: A group of construction industry professionals on the project. They include but are not limited to architects, engineers, contractors, sub-contractors, artisans etc.

NB: You may leave out questions that are not relevant to your project or pick 0% where the question DID NOT influence/impact the project selected for the questionnaire.

BROAD OVERVIEW

18. SECTION A

Based on the project you selected, how do the under-listed factors influence the decision to adopt or reject OSC on the project? Your knowledge/understanding of this may be from any source on the project, e.g., a direct relationship with the project, client, board members, any other project stakeholders, or team members, amongst many others. It does not matter whether it led to a positive or negative outcome on the project, **what is important is to what extent the factor was considered**. For instance, **high consideration** attracts scale 5 and **low consideration** attracts scale 1.

Please use the ratings below to select your best options:

1 = 0% (Not considered at all) **2** = 1% -25% (Low consideration) **3** = 26% -50% (Medium-Low consideration)

4 = 51% -75% (Medium-High consideration) **5** = 76% -100% (High consideration)

1 = 0% (Not considered at all) **2** = 1% -15% (Very Low consideration) **3** = 16% - 30% (Low consideration) **3** = 31% -45%

(Mild consideration) **4** = 46% -55% (Average consideration) **5** = 55% -70% (Good consideration) **6** = 71% -85%

(High consideration) **7** = 86% -100% (Very High consideration)

S/No		INFLUENCING FACTORS	1	2	3	4	5
1	Awareness	Awareness of client-related stakeholders on the potential (benefits) of using OffSite Construction (OSC) for this project? E.g., investors, financiers, clients, etc.					
2		Awareness of professional stakeholders on the possibilities of using OSC for this project or not? E.g., architects, engineers, contractors, consultants, and artisans, etc.					
3		Awareness of project end-users regarding the decision to adopt OSC on the project or not to.					
4		Awareness of planning authorities: How much consideration was given to the influence the level of knowledge planning authorities possesses about the construction methodology involving OSC have on approval decision for the project?					
5		Awareness of Construction product manufacturing companies: To what extent was the knowledge of OSC project component/module production considered when planning the project?					
6	Project Team and change management	How much consideration was given to assembling the whole OSC project team for this project (not just a sub-team the respondent is part of)?					
7		How much consideration was given to project team's readiness to utilize OSC for the project?					
8		How much consideration was given to project team's possible request to use OSC for the project or not?					
9		How much consideration was given to Project team's competence to use OSC?					
10		How much consideration was given to contractor's proficiency to effectively implement the OffSite project being considered?					
11		How much consideration was given to availability of training for project team members on the use of OSC for the project?					

12		How much consideration was given to Awareness, Desire, Knowledge, Ability and Reinforcement (ADKAR) approach in the use of OSC for projects					
13		How much consideration was given to availability of past OSC Project Data to support adopting OSC for the project or not?					
14		How much consideration was given to availability of past OSC Project Data to support adopting OSC for the project or not?					
15		How much consideration was given to OSC's project collaboration and information sharing platforms (communication platforms e.g., email, collaboration software, project management tools) for project team members?					
16		How much consideration was given to OSC's possibilities to generate and collate post-construction data for monitoring, evaluation, and reporting					

19. How much consideration was given to the under-listed factors in the decision to adopt OSC for the project you chose. It does not matter if it led to a positive or negative outcome on the project, **what is important is to what extent the factor was considered**. For instance, **high consideration** for reluctance attracts scale 5 and **low consideration** for resistance attracts scale

1. Please use the ratings to select your best options:

1= 0% (Not considered at all) 2 = 1% -25% (Low consideration) 3 = 26% -50% (Medium-Low consideration) 4 = 51% -75% (Medium-High consideration) 5 = 76% -100% (High consideration)

	Percep	Negative historical perception of OSC/prefabricated buildings on the project (the mindset that OSC could fail like it did when it was first used around mid 1900s to resettle war soldiers and their families after WWII.)					
1	tion						
2		The quality perception of OSC/prefabricated projects (a belief that OSC quality is not as good as traditional construction projects)					
3		Durability perception of OSC buildings (a mindset that traditional buildings are more durable than OSC buildings) on the project					
4		Cost perception (a belief that OSC is more expensive than traditional construction project) on the project					
5		Monotonous perception (a mindset that OSC can only do box designs, that it is not good for creative or flexible designs)					
6		End-users' perception of OSC buildings on the project					
7		Perception of real estate professionals in terms of how end-users, e.g., rentals, may view the use of OSC on the project.					
8	Attitu	Conservative Attitude of project stakeholders and team (Preference for well-known Traditional Method over OSC as a new method of construction)					
9	de	Protectionism (Fear of the unknown regarding adopting OSC for the project)					
10		The reluctance of client-related stakeholders to change from the traditional method of construction					
11		The reluctance of professional stakeholders to change from the traditional method of construction					
12		Resistance from client-related stakeholders to adopting OSC for the project					
13		Resistance from professional stakeholders to adopting OSC for the project					
14		Resistance from end-users to adopting OSC for the project					

20. Based on the project you selected, how much impact do the under-listed factors have on the decision to adopt or reject the use of OSC on the project? It does not matter if it led to a positive or negative outcome on the project, **what is important is to what extent the factor impact the decision taken**. For instance, **high impact** attracts scale 5 and **low impact** attracts scale

1.

OSC Doctoral Thesis

Please use the ratings to select your best options:

1= 0% (No impact) **2** = 1% -25% (Low impact) **3** = 26% -50% (Medium Low Impact) **4** = 51% -75% (Medium High impact) **5** = 76% -100% (High impact)

		SECTION B	1	2	3	4	5
1	Design and construction	Design lead time (Is the amount of time required before freezing OSC design quicker or slower)					
2		Design and construction flexibility (Are OSC designs well adaptable to changes as traditional designs?)					
3		Designers' OSC designing abilities (How well do designers meet OSC production requirements)					
4		OSC Building (Construction) material quality (a belief that OSC construction material is not of the quality as traditional construction material)					
5		OSC Building (Construction) material durability (a belief that OSC construction material is not as durable as traditional construction material)					
6		OSC type used (How much consideration was given to OSC type e.g., volumetric, panel, pods, or components?)					
7		Building type (In deciding for OSC, how much consideration was given to project building type e.g., private, bespoke, commercial, institutional, etc.)					
8		Ease of on-site OSC components/modules assemblage					
9		Buildability of the project design (How much did you consider how buildable the OSC design is for the project)					
10		Scalability (Repeatability of design and project modules)					
11		Standardization of modules					
12		Structural Performance of connected modules					
13		Production quality control					
14		OSC components tolerances					
15		Timesaving (Speed, possibilities of overlapping schedules during production, quick on-site works)					

21. For questions/factors below, tick the response that best characterises the percentage you will give each statement with respect to your chosen project, where **1** = 0 - 20% availability, **2** = 21 - 40% availability, **3** = 41 - 60% availability, **4** = 61 - 80% availability and **5** = 81 - 100% availability.

C		SECTION C	1	2	3	4	5
1	Supply chain and Logistics	Supply Chain Management					
2		Availability of manufacturing company(ies), nearby or far away, that can produce the project's desired OSC modules or components					
3		A secured pipeline of work (the ability of the production company to meet project demands during the project period)					
4		Transportation means for components or modules					
5		Consideration/Availability for Specialist equipment and tools such as Crane management on site					

22. For question below, tick the response that best characterises the percentage you will give the availability of each statement, where **1** = 0 - 20%, **2** = 21 - 40%, **3** = 41 - 60%, **4** = 61 - 80% and **5** = 81 - 100%.

1		Truck size that fits module/component size					
2		Road width that fits truck size					
3		Access Road to the site that fits truck size					
4		Number of access available to the project site					
5		Ratio of site size to buildable area					
6		Site Hedging (Availability of site storage area for components and modules)					

23. How would you rate the impact of the underlisted factors have on the OSC project you chose for this questionnaire?

1= 0% (No impact) 2 = 1% -25% (Low impact) 3 = 26% -50% (Medium Low impact) 4 = 51% -75% (Medium High impact) 5 = 76% -100% (High impact)

10		Unfavourable weather conditions during project period					
11		Redundancy of local workers (Were you worried about how many construction workers would be jobless if OSC was adopted?)					
12		Shortage of skilled OSC workers					

24. Based on the project you selected, what level of consideration was given to the underlisted factors in the decision to adopt or reject the use of OSC on the project? It does not matter if it led to a positive or negative outcome on the project. For instance, **high consideration** attracts scale 5 and **low consideration** attracts scale 1.

Please use the ratings to select your best options:

1= 0% (No consideration) 2 = 1% -25% (Low consideration) 3 = 26% -50% (Medium Low consideration) 4 = 51% -75% (Medium High consideration) 5 = 76% -100% (High consideration)

13	Demand for OSC	Client's expression of preference for a construction method (use of OSC or traditional method) on the project					
14		Category of the client (e.g., private individual client, private corporate client, public sector client, etc.) influence on the decision to adopt or not adopt OSC for the project. (Client type)					
15		End-user's demand for a specific construction methodology (to adopt or not adopt OSC) on the project.					
16		Top management members' preference for use of OSC on the project or not					

25. To what extent were the under-listed factors considered in the decision to adopt OSC for the project. It does not matter if it led to a positive or negative outcome on the project, **what is important is to what extent the factor was considered**. For instance, **high consideration** for reluctance attracts scale 5 and **low consideration** for resistance attracts scale 1. Please use the ratings to select your best options:

1= 0% (Not considered at all) 2 = 1% -25% (Low consideration) 3 = 26% -50% (Medium-Low consideration) 4 = 51% -75% (Medium-High consideration) 5 = 76% -100% (High consideration)

D		SECTION D	1	2	3	4	5
1	Policies and regulations	Planning regulations on OSC applications in relation to traditional construction applications?					
2		Government policy on construction projects, e.g., policies on saving 33% cost, 50%-time, net-zero carbon reduction, achieving 55% premanufactured value (PMV) etc.					
3		Government regulations (e.g., restrictions on heights, number of floors, etc.)?					
4		Government incentives (How much consideration was given to encouraging rewards on the use of OSC e.g., issuing of green card, BREEAM cert (UK LEED version), on the use of OSC in relation to traditional construction?)					
5		Availability of dedicated OSC construction regulations, monitoring and inspection.					
6	Sustainability	Availability of industry practice guidelines on use of OSC for projects					
7		Environmental Sustainability (How much of OSC sustainability impact did you consider in adopting OSC for the project)					
8		OSC Building whole life cycle (Overall OSC building performance during building lifetime when compared with traditional construction)					
9		Energy efficiency					

10		Carbon emission					
11		Waste reduction					
12		Safety consideration					

26. To what extent were the under-listed factors considered in the decision to adopt OSC for the project. It does not matter if it led to a positive or negative outcome on the project, **what is important is to what extent the factor was considered**. For instance, **high consideration** for reluctance attracts scale 5 and **low consideration** for resistance attracts scale 1. Please use the ratings to select your best options:

1= 0% (Not considered at all) 2 = 1% -25% (Low consideration) 3 = 26% -50% (Medium-Low consideration) 4 = 51% -75% (Medium-High consideration) 5 = 76% -100% (High consideration)

E		SECTION E					
1	Construction industry market	Client's business model					
2		Developer's business model					
3		OSC Contractor's Business Model (How suitable was the OSC business model for the project)					
4		UK construction industry market readiness for OSC buildings					
5		Nature of the construction industry (fragmented and complex)					
6		Availability of construction industry SMEs' support for the OSC project					
7		Financial viability of OSC projects					
8	Cost issues	Overall OSC project cost					
9		Initial setting up cost (1st instalment paid to kick start the project)					
10		Cost-saving potentials of using OSC for the project					
11		Cost control advantage of OSC during the project duration					
12		Cost certainty for adopting OSC on the project					
13		Funding (Securing funds for adopting OSC on the project)					
14		Securing Insurance (concerning adopting OSC on the project)					
15		Mortgage Accessibility (with respect to adopting OSC on the project)					

27. Should there be any issues you feel have been left out, kindly note them below. You may apply the criticality scale 1-5, where 5 is the most critical and 1 is the least critical to your comments(s) where it applies. Thank you.

.....

Thank you for attempting to attend to this questionnaire. Your efforts are very appreciated.

Have you been involved in any other OSC project within the UK?

Yes **No**

If No, go to appreciation and close survey.

If Yes:

Would you be happy to use the information of the project in filling the survey questionnaire again?

Yes No

If No, go to appreciation and close survey. If yes, return to A- Pre-Requisites to commence another survey filling.

I sincerely want to appreciate you for your painstaking sacrifice in filling out this form and helping contribute to knowledge development on Offsite Construction (OSC). Thank you very much.

Wusu Godoyon

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APPENDIX 10: Details of Dropped Features Mapped to Kept Feature

Table 7.1b: Details of Dropped Features Mapped to Kept Features (Multi-Class Classification using KNN Imputation)

Dropped Feature	Kept Feature	Correlation Value
PA7	PA6	0.882
CMC5	CMC4	0.714
CMC2	CMC1	0.766
PP3	PP2	0.776
PRS4	PRS3	0.706
DCF5	DCF4	0.731
SCL14	SCL13	0.816
PA2	PA1	0.712
PD4	PD3	0.853

Table 7.1c: Details of Dropped Features Mapped to Kept Features (Binary Classification using Mode Imputation)

Dropped Feature	Kept Feature	Correlation Value
PA2	PA1	0.712
PKD3	PKD2	0.701
CMC2	CMC1	0.761
CMC5	CMC4	0.714
SCL14	SCL13	0.815
PD4	PD3	0.853
DCF5	DCF4	0.728
PA7	PA6	0.88
PP3	PP2	0.771
PRS4	PRS3	0.706

Table 7.1d: Details of Dropped Features Mapped to Kept Features (Binary Classification using KNN Imputation)

Dropped Feature	Kept Feature	Correlation Value
PKD3	PKD2	0.703
DCF5	DCF4	0.731
PA7	PA6	0.882
PP3	PP2	0.776
SCL14	SCL13	0.816
CMC2	CMC1	0.761
PA2	PA1	0.712
CMC5	CMC4	0.713
PD4	PD3	0.853
PRS4	PRS3	0.706

APPENDIX 11: Top 25 Features Selected from each feature Selection Method Approach

Table 7.61a: Top 25 features selected from each FS Method Approach (A case of MCC using Mode missing data imputation)

S/N o	Chi-Square (One-Hot)	ANOVA Features	Ordinal Regression	Logistic Features	RFE Features	Lasso (One- Hot)	Permutation Importance	XGBoost Importance	Spearman Correlation	Mutual Information	Information Gain
1	AW2	AW4	PP5		AW4	PRS8	DCF12	PD11	AW4	AW2	GF2
2	AW4	CMC15	DCF11		CMC6	AW4	DCF13	PD8	PD9	CMC14	PD9
3	CMC15	CMC4	PTM1		CMC7	CMC15	DCF14	PD5	SCL8	CMC3	SCL7
4	CMC6	CMC6	SCL8		CMC8	PP7	PD10	PD3	SCL7	CMC7	SCL12
5	CMC9	CMC9	PTM4		CMC9	SCL10	PD1	PD6	CMC4	DCF1	PD8
6	DCF1	DCF1	GF2		DCF10	PD3	PA6	SCL8	PKD2	DCF10	GF1
7	DCF10	DCF10	CMC13		DCF11	PP5	PA5	PA6	PP5	DCF11	CMC15
8	GF1	DCF15	AW4		DCF4	PP1	PA4	AW2	SCL10	DCF2	PKD2
9	PD11	DCF4	PRS8		PA1	DCF10	PA3	SCL11	PD3	DCF3	PP7
10	PD3	PD11	DCF8		PA4	SCL8	PA1	AW4	DCF10	DCF7	PTM2
11	PD5	PD3	DCF12		PA5		GF5	PRS1	DCF15	GF1	PRS6
12	PD9	PD5	SCL13		PA6		GF4	SCL7	PRS8	GF5	DCF4
13	PKD2	PD8	PD6		PD11		SCL8	CMC10	SCL11	PA3	CMC6
14	PP1	PD9	PD9		PD8		GF3	PTM3	CMC6	PA5	DCF10
15	PP5	PKD2	DCF15		PKD1		GF1	CMC9	DCF1	PD10	SCL9
16	PP7	PP5	PA4		PKD2		DCF9	CMC15	CMC13	PD8	GF4
17	PRS1	PRS3	PRS1		PKD4		DCF8	PD7	AW1	PD9	PRS2
18	SCL11	SCL10			PP5		DCF7	SCL12	PD11	PKD2	PRS10
19	SCL7	SCL11			PRS8		DCF6	CMC8	PRS6	PP7	PD11
20	SCL8	SCL13			PTM1		DCF4	DCF1	CMC1	PRS12	SCL13
21		SCL5			PTM6		DCF3	PTM1	CMC9	PRS2	PTM5
22		SCL6			SCL10		DCF2	PKD2	CMC15	PRS8	DCF6
23		SCL7			SCL5		DCF15	PP4	GF5	PTM3	DCF3
24		SCL8			SCL8		GF2	CMC6	PRS3	SCL11	PP1
25		SCL9			SCL9		SCL9	PTM2	AW3	SCL7	CMC7

Table 7.72b: Top 25 features selected from each FS Method (A case of MCC using KNN missing data imputation)

S/ No	Chi-Square (One-Hot)	ANOVA Features	Ordinal Logistic Regression	RFE Features	Lasso (One- Hot)	Permutation Importance	XGBoost Importance	Spearman Correlation	Mutual Information	Information Gain
1	AW2	AW4	PP5	AW4	DCF2	DCF12	PD11	AW4	AW1	PD9
2	AW4	CMC15	DCF11	CMC6	SCL11	DCF13	PD5	SCL8	CMC15	GF1
3	CMC15	CMC4	SCL8	CMC8	CMC13	DCF14	DCF1	PD9	CMC3	SCL7
4	CMC6	CMC6	PTM4	CMC9	SCL7	PD10	SCL8	PKD3	CMC8	PKD3
5	CMC9	CMC9	GF2	DCF10	PKD3	PD1	SCL7	SCL7	DCF1	PRS6
6	DCF1	DCF1	DCF8	DCF12	PKD1	PA6	PRS7	PP5	DCF13	CMC3
7	DCF10	DCF10	CMC13	DCF14	PD9	PA5	PD6	CMC4	DCF14	PD2
8	GF1	DCF15	PTM1	DCF4	CMC9	PA4	PA6	PKD2	DCF3	PP7
9	PD11	DCF4	PRS8	PA4	PP1	PA3	PRS5	SCL10	DCF4	PD8
10	PD3	PD11	DCF12	PA5	PKD2	PA1	PD3	DCF10	GF2	CMC15
11	PD5	PD3	AW4	PA6	GF3	GF5	PRS11	PD3	GF5	PTM3
12	PD9	PD5	SCL13	PD11	CMC15	GF4	CMC12	DCF15	PA3	GF2
13	PKD2	PD8	PD6	PKD1	PD8	PD2	DCF7	SCL11	PD11	PTM2
14	PKD3	PD9	PA4	PKD2	PTM4	GF3	AW4	PRS8	PD8	CMC6
15	PP1	PKD2	PD9	PKD3	PP7	GF1	CMC9	CMC13	PD9	SCL9
16	PP5	PKD3	DCF15	PKD4	AW4	DCF9	SCL12	PRS6	PKD1	PD11
17	PRS1	PRS3		PP5	PRS8	DCF8	PD8	DCF1	PKD2	GF3
18	SCL11	SCL10		PRS8	PD2	DCF7	PD7	PD11	PKD4	PRS1
19	SCL7	SCL11		PTM1	SCL10	DCF6	CMC13	AW1	PP6	SCL12
20	SCL8	SCL13		PTM4	PD3	DCF4	CMC10	CMC6	PTM1	DCF1
21		SCL5		PTM6	PP5	DCF3	PKD4	CMC1	SCL11	PKD2
22		SCL6		SCL10	DCF10	DCF2	PTM3	CMC15	SCL13	PKD4
23		SCL7		SCL5	SCL8	DCF15	AW2	CMC9	SCL7	PD5
24		SCL8		SCL8		GF2	CMC6	AW3	SCL8	SCL11
25		SCL9		SCL9		SCL9	PTM2	GF5	SCL9	DCF10

Table 7.82c: Top 25 features selected from each FS Method (A case of BC using Mode missing data imputation)

S/ No	Chi-Square (One-Hot)	ANOVA Features	Binary Logistic Regression	RFE Features	Lasso (One-Hot)	Permutation Importance	XGBoost Importance	Spearman Correlation	Mutual Information	Information Gain
1	CMC9	AW1	PTM6	DCF12	PP7	AW5	SCL7	SCL7	DCF14	SCL7
2	DCF1	CMC9	AW4	SCL7	PKD4	PP7	AW4	SCL8	SCL7	PP5
3	SCL7	DCF1	CMC11	SCL8	SCL10	PD1	SCL11	PKD2	SCL8	SCL11
4	SCL8	SCL7	PD3	AW4	PKD2	CMC3	DCF3	SCL10	AW4	AW4
5	AW4	SCL8	DCF1	SCL5	DCF10	PRS11	PRS5	AW4	PRS7	DCF7
6	PP5	AW4	PRS1	PP5	SCL7	PTM1	PRS12	SCL11	SCL5	CMC8
7	PKD1	SCL5	DCF4	DCF8	PD2	DCF13	DCF13	DCF1	PP7	CMC7
8	SCL10	SCL3	AW3	SCL10	PP5	PP6	SCL8	DCF10	PP5	PRS6
9	PD2	AW5	PTM2	SCL9	SCL8	SCL11	DCF8	CMC6	DCF3	PD9
10	SCL11	PP5	SCL7	PA4	PP1	PA4	SCL10	DCF4	PKD1	PD2
11	PD8	DCF3	DCF8	SCL13		PTM5	DCF10	CMC4	PRS6	CMC6
12	DCF15	SCL10	SCL10	PA1		SCL9	PD11	DCF15	PA4	PP7
13	DCF10	PRS6	DCF11	DCF10		PRS8	PTM3	SCL6	SCL6	AW5
14	PP1	SCL9	CMC8	PA6		PD2	PKD2	SCL5	DCF6	DCF1
15	CMC6	SCL11	CMC7	PKD4		PRS6	PP1	CMC9	CMC1	PP2
16	PRS1	SCL6	PA5	PTM6		DCF11	GF5	PP5	PA6	PP4
17	GF1	DCF15	SCL5	DCF7		PKD1	DCF1	AW3	CMC6	PP1
18	DCF4	DCF10	PA4	CMC8		DCF8	PD2	PRS6	PRS5	PRS7
19	PKD2	CMC6	PA1	PRS3		DCF3	DCF9	SCL3	AW3	PTM4
20		DCF7	PKD4	PTM2		PP5	PP5	AW1	CMC10	DCF3
21		AW3	DCF12	PA5		AW2	DCF12	PKD1	CMC14	PTM3
22		CMC4	SCL13	PTM4		PP4	PRS10	SCL9	PA3	GF2
23		DCF4	PTM4	DCF4		PRS12	SCL12	CMC1	DCF4	PRS1
24		PKD2	SCL8	PKD2		CMC13	PA5	DCF2	DCF2	SCL10
25		DCF2	PP5	PRS8		SCL10	AW3	DCF7	CMC15	CMC1

Table 7.92d: Top 25 features selected from each FS Method (A case of BC using KNN missing data imputation)

S/ No	Chi-Square (One-Hot)	ANOVA Features	Binary Logistic Regression	RFE Features	Lasso (One-Hot)	Permutation Importance	XGBoost Importance	Spearman Correlation	Mutual Information	Information Gain
1	AW4	AW1	DCF1	AW4	PP7	SCL9	SCL7	SCL7	AW1	SCL7
2	CMC6	AW3	PD3	CMC8	PKD4	DCF14	AW4	SCL8	CMC1	PP5
3	CMC9	AW4	PRS8	DCF10	SCL10	PD10	PRS10	PKD2	CMC3	PD9
4	DCF1	CMC4	PTM6	DCF12	PKD2	PD1	PD2	SCL10	DCF1	AW4
5	DCF10	CMC6	AW4	DCF13	SCL7	PA6	DCF12	SCL11	DCF2	SCL11
6	DCF4	CMC9	DCF4	DCF4	PP5	PA5	SCL8	DCF10	DCF3	PD2
7	GF1	DCF1	CMC11	DCF8	PD2	PA4	PRS12	AW4	DCF8	PKD1
8	PA5	DCF10	SCL7	PA1	DCF10	PA3	CMC1	DCF1	PA5	CMC1
9	PD2	DCF15	AW3	PA4	SCL8	PA1	DCF7	CMC6	PD10	DCF4
10	PKD1	DCF2	SCL10	PA5	PP1	GF5	DCF10	DCF4	PD6	PTM2
11	PKD2	DCF3	PTM2	PA6		GF4	AW3	DCF15	PKD1	PP7
12	PP1	DCF4	DCF8	PKD2		DCF13	PKD2	CMC4	PKD2	DCF1
13	PP5	DCF7	DCF11	PKD4		GF3	DCF1	SCL5	PKD4	PKD4
14	PRS1	PKD2	CMC8	PP5		GF1	PP5	SCL6	PKD5	DCF12
15	SCL10	PP5	CMC7	PRS1		DCF9	SCL10	CMC9	PP5	PP2
16	SCL11	PRS6	SCL5	PRS8		DCF8	PA3	AW3	PP6	PP4
17	SCL7	SCL10	PA5	PTM2		DCF7	GF5	PKD1	PRS1	PP1
18	SCL8	SCL11	PA1	PTM4		DCF6	DCF8	PP5	PRS11	PTM3
19		SCL3	PA4	PTM6		DCF4	PRS2	PRS6	PRS5	PKD2
20		SCL4	PKD4	SCL10		DCF3	SCL11	SCL3	PRS9	DCF3
21		SCL5	DCF12	SCL13		DCF2	PP6	AW1	SCL10	PRS1
22		SCL6	SCL13	SCL5		DCF15	PP1	SCL9	SCL11	SCL10
23		SCL7	PTM4	SCL7		GF2	PTM3	CMC1	SCL12	GF2
24		SCL8	PP5	SCL8		SCL7	DCF13	DCF2	SCL7	CMC7
25		SCL9	SCL8	SCL9		SCL8	CMC8	DCF7	SCL8	GF1

