OPERATIONALISATION OF OFFSITE MANUFACTURING OF CONCRETE BUILDING ELEMENTS IN BUILDING CONSTRUCTION PROJECTS IN NAIROBI

RESEARCH PROJECT

BY

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A research project submitted in partial fulfilment of the requirement for the degree of Masters of Arts in Construction Management in the Department of Real Estate, Construction Management & Quantity Surveying at the University of Nairobi.

June, 2022

DECLARATION

This research project is my work and has not been presented in any other university or institution for the purpose of awarding a degree to the best of my knowledge.

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SUPERVISOR

I confirm this research project has been submitted for examination with my approval as the university supervisor.

Signature: .... Date: 28.06.2022

Prof. Robert Rukwaro

DEDICATION

I dedicate this study to my late parents, for all the values you instilled in me.

ACKNOWLEDGEMENT

Very many thanks to:

My research project supervisor Prof. Robert Rukwaro,

All respondents who participated in this study,

The staff, Department of Real Estate, Construction Management & Quantity Surveying, University of Nairobi,

MA Construction Management classmates,

My partner Michi.

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ABBREVIATIONS AND ACRONYMS

ABMTs: Alternative Building Materials and Technologies

ACT : Alternative Construction Technologies

AEC : Architecture, Engineering and Construction

BIM : Building Information Modeling

CNC : Computer Numerical Control

EPR : Extended Producer Responsibility

IBS : Industrialised Building System

JIT : Just In Time

KeNHA: Kenya National Highways Authority

LEED : Leadership in Energy and Environmental Design

MMC : Modern Methods of Construction

NCA : National Construction Authority

NCC : Nairobi City County

NEMA: National Environment Management Authority

NMS : Nairobi Metropolitan Services

OSC : Offsite Construction

OSF : Offsite Fabrication

OSM : Offsite Manufacturing

OSP : Offsite Production

SCM : Supply Chain Management

SD : Standard Deviation

SPSS : Statistical Package for Social Sciences

UPVC : Unplasticized Polyvinyl Chloride

ABSTRACT

Offsite manufacturing of concrete building elements in building construction projects offers quite significant advantages over onsite methods. This study aimed to identify the types of OSM of concrete building elements used in building construction projects in Nairobi; identify the parameters that influence positively and negatively the use of these OSM concrete building elements; establish parameters that need to be considered in the decision-making to use OSM concrete building elements; and establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi. The study was conducted through a cross section survey method. Primary data was collected from consultants (project managers, architects, structural engineers and quantity surveyor), developers, contractors, manufacturers, and other stakeholders in the built environment by administering questionnaires, conducting interviews and visiting active building construction projects and offsite manufacturing facilities to make observations. The analysis of the data collected was done using SPSS and Microsoft Excel. The research was based on the following variables: cost; schedule/time; labour and productivity; scope; quality, predictability and reliability; risk; research and development; and sustainability (environmental dimension, social dimension, cultural dimension, economic dimension). Other parameters were included that were not captured by these variables. The findings show: it is only the non-volumetric type of OSM concrete building elements that are used; low usage of OSM concrete building elements; the parameters adopted from the variables all need to be considered in the decision-making to use OSM concrete building elements; and the strategies proposed were very highly considered as appropriate that can be implemented to increase the use of OSM concrete building elements in building construction projects in Nairobi. These strategies formed part of the recommendations.

CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

Smith (2017) refers to OSC as "the manufacturing, planning, design, fabrication, and assembly of building elements at a location other than their final installed location to support the rapid speed and efficient construction of a permanent structure". These building elements could be manufactured in a different location from the site and transported to the site, or they may be manufactured on the site and transported to their final installation location within the site. OSC is distinguished by a strategy of integrated planning and optimization of supply chain.

Majority of design drawings and specifications done by the design team in a traditional contracting system tend to be oriented on a performance basis, specifying the final product and materials whilst leaving the methodology of construction to the contractor. As a result, the reality of construction is that the majority of problems experienced on the site like delays, re-works and low quality or productivity, are frequently compounded by innate design shortfalls caused at the design stage. Implementing the concept of constructability is another way to overcoming the problem. Constructability is frequently depicted as incorporating construction knowledge, resources, technology, and experience into a project's engineering and design (Nawi *et al*. 2011).

Constructability is the best use of construction knowledge and experience during the conceptual planning, detail engineering, procurement, and field operations phases to achieve overall objectives of the project (Construction Industry Institute 1986). It is also identified as the incorporation of construction expertise into project planning and design (Mendelsohn 2002, cited in Nawi *et al*. 2011).

Pan, Gibb and Dainty (2012) note that in spite of immense research conducted on attitudes and practice encompassing the adoption of OSM technologies, there is a lack of understanding of how to best consolidate their use into business processes at the organizational level. In their study that investigated the processes whereby OSP technologies were adopted and utilised, (Pan, Gibb and Dainty 2012) conclude that their adoption and utilization was structured fundamentally by the housebuilding business process four fundamental stages (of land acquisition, pre-site, onsite and postsite), and seven business milestone review stages (of land, planning, budget, start on site, five months into build, six months after completion or three months after final legal completion, and two years warranty & handover).

Looking at Kenya, according to the World Bank (2021), Kenya's National Development Plan and Vision 2030 Strategy aims to provide 200,000 housing units per year for people of all levels of income. Although, housing unit production is less than 50,000 housing units per year currently, way under the target, resulting in a shortage of over two million housing units, with almost 61% of urban households living in slums. This shortage is growing due to fundamental challenges to demand and supply and is aggravated by a 4.4% urbanization rate equating to half a million new residents in the city annually.

Kenya can make housing, and construction in general, more affordable. This can be achieved through the promotion of adoption of the appropriate offsite manufacturing techniques in building construction projects, promotion of adoption of ABMTs, and adoption of appropriate financing models. This will in turn open up new avenues for boosting overall growth of the economy. Several stakeholders face challenges to adopt these technologies into their projects. What are the constraints to the adoption of offsite concrete works manufacturing techniques in building construction projects? Specifically in Nairobi? This study set out to establish responses to this question amongst others.

1.2 Statement of the Problem

Nairobi City has a population of over four million, with a growth rate of 3.81% annually. The majority of housing is rented with almost 34% of the households renting a single room in informal settlements, and another 36% living in single room tenements (Mwau, Sverdlik and Makau 2019).

According to the UN Habitat (2005), Nairobi City has the highest annual growth rates on the continent, with the informal settlements absorbing 75% of the urban population growth. In the coming 15 years, the population of urban slum dwellers will double. Informal settlements account for 5% of the city's total residential land area, but they house at least 50% of the city's population.

Noppen (2012) notes that Nairobi requires at least 120,000 new housing units per year to meet demand, but only 35,000 are built, resulting in an 85,000-unit annual housing deficit. Lower income residents are pushed out of the formal housing market into slums as a result. There are numerous approaches to addressing these dynamics, such as housing supply, end-user financing, or new building technologies.

Construction Review Online (2021b) notes that the housing deficit can be made manageable through offsite manufacturing. The use of OSM concrete building elements in building construction projects has not made as much progress on the continent in comparison to the rest of the world. Noppen (2012) further notes that Kenyans have been slow to adopt alternative technologies, favoring traditional techniques and technologies. Kenya, and Nairobi in particular, are not alone in this regard as marketing alternative techniques has been a challenge worldwide. This study, amongst other objectives as stated below, sought to establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

1.3 Objectives of the Study

The study's main objective was to identify the parameters that influence positively and negatively the decision-making to use offsite manufacturing of concrete building elements in building construction projects in Nairobi. The specific objectives are:

i. To identify the types of OSM concrete building elements used in building construction projects in Nairobi.
ii. To identify the parameters that influence positively the decision to use OSM concrete building elements in Nairobi.
iii. To identify the parameters that influence negatively the decision to not use OSM concrete building elements in Nairobi.
iv. To establish parameters that need to be considered in the decision to use OSM concrete building elements in Nairobi.
v. To establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

1.4 Research Questions

The study aimed to provide answers to the following questions:

i. Which OSM concrete building elements are used in building construction projects in Nairobi?
ii. What parameters influence positively the decision to use OSM concrete building elements in Nairobi?
iii. What parameters influence negatively the decision to not use OSM concrete building elements in Nairobi?
iv. What parameters need to be considered in the decision to use OSM concrete building elements in Nairobi?
v. What appropriate strategies can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi?

1.5 Study Hypothesis

The directional hypotheses below were proposed to increase the understanding of the parameters that influence positively and negatively the decision to use OSM concrete building elements in building construction projects in Nairobi:

Hypothesis 1: Schedule/time and quality, predictability and reliability influence positively the decision to use offsite manufacturing of concrete building elements.

Hypothesis 2: Cost, labour & productivity, scope and risk influence negatively the decision-making to not use offsite manufacturing of concrete building elements.

Hypothesis 3: Taxation subsidies on materials and retraining & reskilling of labour force strategies can increase the adoption of offsite manufacturing of concrete building elements when implemented.

1.6 Justification of the Study

Having acknowledged the low adoption of offsite manufacturing of concrete building elements in building construction projects, it was imperative to establish the constraints that lead to this low rate and further establish appropriate strategies that can be implemented to increase the adoption, specifically in Nairobi.

Mwau, Sverdlik and Makau (2019) note that the planning systems of Nairobi have to be improved so that the needs of the city's low-income majority are better met and respond to the city's complex market of informal housing. As a positive first step, affordable housing was recently named one of Kenya's "Big Four" policy priorities, and the president pledged to build half a million affordable homes by year 2022, opening the door to more inclusive strategies.

Gibb (1999) notes that in the past few years, the manufacturing sector has made important advancements, especially in information technology, robotics, quality control and supply chain management. The construction sector seems to lag behind in terms of implementing these advancements. Benefits of OSM can be taken into building construction. Several automobile manufacturers in Japan are now including OSM residential units in their portfolios, maximizing the return on investment in manufacturing capacity.

To push the country's affordable housing agenda forward, appropriate strategies need to be implemented to increase adoption of the adoption of ABMTs and most especially OSM techniques. This will also lead to an increase of housing units into the market within shorter timeframes. Chapter two discusses these techniques in detail.

1.7 Significance of the Study

Findings from the study helped establish parameters that need to be considered in the decision-making to use OSM concrete building elements and establish the suitable strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

This study is a collated reference document with information on factors that need to be considered in the adoption of offsite manufacturing of concrete building elements to counter the constraints faced, and the suitable strategies that can be implemented by various built environment stakeholders (the government – both at national and county levels, regulatory authorities, developers, consultants, contractors, manufacturers and the general public who are regarded as users of the spaces created) to increase the use of offsite manufacturing of concrete building elements.

1.8 Assumptions of the Study

The research assumed:

i. There are various offsite manufacturing of building elements used in Nairobi.

ii. There are various types of offsite manufacturing of concrete building elements used in Nairobi.
iii. The adoption of the offsite manufacturing of concrete building elements by the various construction stakeholders was generally low, with constraints faced to which strategies to increase the adoption were established in the study.

1.9 Scope and Limitations of the Study

This study only conducted an evaluation of offsite manufacturing of concrete building elements, as there are other forms of offsite manufacturing of building elements such as timber, steel, UPVC, PVC, etc.

The study was geographically limited to Nairobi City County. Nairobi has the highest annual growth rates in Africa of 3.81%. Nairobi, Kenya's largest city, has a population of 4,397,073 people according to 2019 census (Kenya National Bureau of Statistics 2019). The city's diversity makes it ideal for this study.

One of the limitations to the study arose from physical unavailability of literature material due to the libraries being inaccessible earlier on in the study due to the measures implemented by the Government of Kenya to aid fight the global Covid-19 pandemic. Overcoming this to ensure valid literature material was by relying on credible digital repositories such as the University of Nairobi's Digital Repository, Journal Storage (JSTOR), UN Habitat, Multidisciplinary Digital Publishing Institute (MDPI) and much more. Complimenting this was buying soft copy versions of the literature material needed.

Another limitation to the study was low responsiveness from the respondents. Overcoming this was reaching out to most of the respondents individually. This ensured the data collected was comprehensive enough to review and report conclusive findings.

Another limitation to the study was time and financial constraints not only to get more responses, but also to increase the study scope to the national level.

1.10 Definition of Key Terms

Building elements refers to a constituent part of a building which has its own functional identity (Rukwaro 2019).

Concrete is structural material made by mixing specific ratio of cement, aggregates, and water and letting the mixture cure under controlled conditions (Allen and Iano 2019).

Constructability is the optimum use of construction knowledge and experience in the conceptual planning, detail engineering, procurement, and field operations phases to achieve the overall project objectives (Construction Industry Institute 1986).

Design-assist is a project delivery method whereby the construction team is engaged by the owner to collaborate with the architect or engineer during the design phase. It is intended to reduce the cost and time for construction, improve constructability and add value (Andre 2012).

Industrialised building system is one in which the components are manufactured in a factory, either on or off site, and then positioned and assembled into a structure with minimal additional site work (CIDB 2003).

Modular is "conforming to a multiple of a fixed dimension" (Allen and Iano 2019).

Offsite construction is the manufacturing, planning, design, fabrication, and assembly of building elements at a location other than their final installed location to support the rapid speed of, and efficient construction of a permanent structure (Smith 2017). Brissi, Debs and Elwakil (2020) use the acronym OSC in order to refer to prefabrication, modular construction and modern methods of construction, in which project components or modules are manufactured in a factory before being transported and assembled on the construction site.

Precast concrete is a construction product produced by casting concrete in a reusable mold or formwork, which is then cured in a controlled environment, transported to the construction site and lifted into place (Construction Review Online 2021a).

Prefabrication is a strategy that uses components made offsite in a factory, which are then transported put together on site to create a structure (Michael Page 2021).

Reinforced concrete refers to concrete work in which steel bars have been embedded to give the structure tensile strength (Allen and Iano 2019).

Shop drawings are detailed drawings produced by fabricators to guide the fabrication of building components as cut stonework, steel or precast concrete framing, curtain wall panels, and cabinetry (Allen and Iano 2019).

1.11 Organization of the Study

Chapter one is an introductory chapter that states the background to the study, statement of the problem, research objectives, research questions, study hypothesis, justification of the study, significance of the study, assumptions of the study, scope & limitations of the study and definition of key terms.

Chapter two incorporates a review of the relevant literature material related to offsite manufacturing of concrete building elements in building construction projects. The chapter also incorporates the conceptual and operational framework.

Chapter three reviews the research methods. The chapter reviews the research design, data sources, sampling design, data collection tools & techniques, data analysis and data presentation.

Chapter four entails a presentation and analysis of the data findings. Data collected from the field and interpretation of the same is discussed here.

Chapter five gives the conclusions and recommendations. A small section of this chapter recommends future areas of further research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter contains a detailed review of literature material applicable to the research problem studied, done through exploring the different theoretical and conceptual approaches. To begin with, is the focus on the theoretical framework, which details the principles that form the basis of this study and empirical review of literature. Thereafter is the conceptual framework section that discusses the variables of the study, which demonstrates the interrelation between the independent variables and dependent variables. The final section gives the operational framework describing the variables, their measures and indicators that will be used to assess the variables and the scales to be used in developing the questionnaires.

2.2 Theoretical Framework

The study focuses on the principles discussed below in the bid to understand offsite concrete works manufacturing in building construction projects. Gibb (1999), Smith (2010), and Smith and Quale (2017) discuss the: offsite manufacturing fundamental theory that has emerged from the Industrial Revolution forward to today; and offsite manufacturing practice uncovering the relationship between offsite prefabrication technology and the contextual conditions in which it is used. Several other authors such as Blismas *et al.* (2005), Blismas (2007), Blismas and Wakefield (2007), Pan, Gibb and Dainty (2012), and Allen and Iano (2019) also discuss ways in which to view prefabrication through unique lenses (design, manufacturing, construction and public opinion) and trace the developments of the offsite manufacturing practice.

2.2.1 Offsite Manufacturing

Wasana, Gunatilake and Fasna (2019) note that with the coming about of new construction technologies, the construction industry's development has accelerated. Among these techniques, prefabricated construction plays a significant role because it has the potential to meet increased demand while also resolving current construction industry challenges.

In comparing industrialised housing to production of automobiles in Japan, Gann (1996) notes that management practices in design, product development, SCM, sales and marketing are used to create industrialized housing and cars, two very different products. The automobile industry's manufacturing principles have been successfully applied to the manufacturing of attractive, customizable, and affordable construction. Nonetheless, such techniques have limitations in their ability to manage the assembly of a wide range of component parts required to manufacture customized products that are complex. Managers have to balance the need for economies of scale in the manufacturing of standardized factory parts with economies of scope in several stages of production so as to meet the preferences of clients. The housing industry can gain from learning more on the application of advanced production techniques developed for automobile manufacturing.

2.2.2 Extent of Offsite Manufacturing

Gibb (1999) notes that the extent of OSM for building construction projects can be determined by taking into consideration the applicable elements listed in Table 2.2.2:1 below and how much work on each of the elements remains to be done on site.

Table 2.2.2:1 Primary elements of most building projects.

Element	**Description**
Substructure	Foundations and works below ground.
Frame	The structure of the building.
Envelope	The external walls and roof that form the perimeter of the building.
Services	The mechanical and electrical building services distribution.
Internal works	The internal walls, raised floors, suspended ceilings and applied finishes such as plaster, paint, wall coverings, etc.
Facilities	The major parts of the building that are generally provided by the developer for the use of the end-user, such as the toilet/washrooms, kitchens, lifts/elevators, plant rooms, building management system rooms, etc.
Complete modular building	Generally, a complete modular building approach is better suited to smaller medium-rise developments. However, various manufacturers are developing systems that can be applied to larger, and taller, buildings.

Source: Gibb (1999).

2.2.3 Types of Offsite Manufacturing

Prefabrication, according to White (1965), is a useful though imprecise term used to describe a trend in building construction technology. White (1965) argues that if OSM were applied to every product made in the factory, then the term would become so broad that it would lose all meaning. In view of this, Gibb (1999) discusses the three types of offsite fabrication established; non-volumetric offsite fabrication, volumetric offsite fabrication and modular building.

2.2.3.1 Non-volumetric Offsite Manufacturing

Gibb (1999) notes that the term non-volumetric could be misleading because all the elements and systems manufactured will have some volume. To distinguish it from volumetric OSM, non-volumetric is used to refer to elements that do not enclose space that is usable. Non-volumetric OSM entails solutions comprising one of the previously mentioned elements in Table 2.2.2:1. Parts of a building's structural frame or cladding, internal partitions, building services parts, distribution ductwork or pipework, and such like are typical examples.

2.2.3.2 Volumetric Offsite Manufacturing

The volumetric OSM category includes units that enclose usable space, but do not of comprise the entire building. Most units are nearly finished, with only a small amount of work remaining to be done on-site. Volumetric OSM is most commonly used for 'facilities', as defined in Table 2.2.2:1, and comprises solutions like office bathrooms, plant rooms, lifts and building services risers. These units are typically installed in a newly built or existing building and are not typically used to give structural support (Gibb 1999).

2.2.3.3 Modular Building

This categorisation includes units that comprise a complete building or a portion of a building, with its structure and envelope. Majority of the units are substantially finished, with little amount of work only remaining to be done on the site. However, some of the systems, particularly for medium-rise construction, provide the structure only and occasionally cladded and finished on the site. For fully done offsite units, this categorisation provide a complete offsite manufactured building; a one-stop system for clients looking for a cost-effective and reasonably simple building. The examples of modular buildings are medium-rise office building, hotel accommodation, housing, stand-alone retail units and a wide range of makeshift or relocatable solutions (Gibb 1999).

2.2.4 Types of OSM Concrete Building Elements

Allen and Iano (2019) notes that structural precast concrete elements such as slabs, beams, girders, columns, roofs, foundations, cladding and wall panels are cast and cured in factories before being transported to the construction site, and erected as rigid components. Precast concrete has potential advantages over site-cast concrete as: it can be produced conveniently at ground level, under shelter, or in a climate-controlled workspaces; operations of mixing and pouring can be highly mechanized; and workmanship can be higher quality and more consistent. The concrete is cast in formwork or moulds made of steel, concrete, glass fiber reinforced plastic, or wood panels with smooth overlays; moulds whose excellent surface properties are mirrored in the high-quality surfaces of the completed elements produced. The moulds can be reused multiple times, hundreds or thousands, before the need to replace them arises bringing down the cost of the moulds.

Constro Facilitator (2020) notes that the various types of precast products have a wide range of applications with their function varying depending on the shape, size, and grade of concrete used. The different types of precast concrete building elements highlighted include: i) foundations – isolated footings, pocket footings, combined footings, precast piles; ii) structural beams – reinforced concrete beams, prestressed beams, shell beams; iii) slabs - reinforced concrete slabs, prestressed hollow core slabs, prestressed solid slabs, double tee slabs, waffle slabs; iv) walls – load bearing external walls, non-load bearing external walls; v) precast joist roof; vi) precast façade panels/cladding; vii) glass fiber reinforced concrete; and other elements – staircase, toilets etc. Other precast concrete elements include; window sills, wall copings, concrete balusters/railings, paving slabs/blocks.

2.2.5 Principles of Offsite Manufacturing

Gibb (1999) notes that achieving the three objectives of time, cost and quality is fundamental to the success of all modern construction projects, especially those that use OSM. Smith (2010) notes that each building construction project must adhere to a number of key principles despite the fact that not all of the concerns could be essential for a particular project. In general, a building has to answer the following construction principles and their effects on productivity: i) cost (capital and operational investment); ii) labour (skilled and unskilled human workforce); iii) time (project's schedule or duration); iv) scope (the project's extent or breadth); v) quality (excellence of the design and construction;) and vi) risk (potential financial loss exposure).

In addition to the principles listed above, Gibb (1999) looks at the following principles: i) predictability and reliability; ii) productivity; iii) safety, health and environment; iv) interfaces and coordination - physical interface, managerial interface, contractual interface and organizational interface; v) implementing innovations from other industries; and vi) re-usability and relocatability.

Smith (2010) notes that by fabricating larger elements of buildings, OSP in construction has the prospect of bringing within reach a balance between cost, schedule and scope. The principles of cost, schedule, and scope are discussed herein under item 2.2.5.1,2,4 and how OSM in particular could be leveraged to attain the balance of the construction principles. The construction triad, as illustrated in Figure 2.2.5:1, is cost, scope (project's extent and breadth) and schedule or project duration. These principles govern the quality and risk of every building construction project.

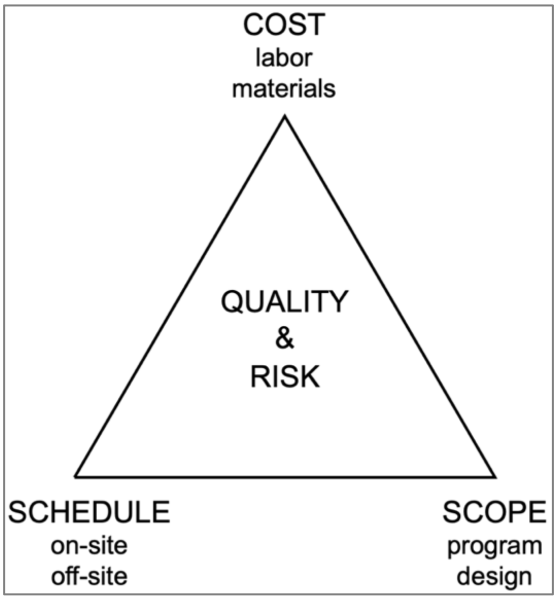


Figure 2.2.5:1 The triad of construction.
Source: Smith (2010).

2.2.5.1 The Principle of Cost

Smith (2010) notes that prefabrication has been promoted as being more cost effective as compared to other onsite construction methods. This is because cost comprises labour, material and time for which prefabrication conceptually has solutions. In theory, if any of these are minimized, cost is minimized as well. However, OSM does not imply a decrease in overall project budget. Actually, a plethora of modern examples use OSM for its precision and increased product quality to achieve greater predictability, but not for its cost-effectiveness, but. Prefabrication must be used intentionally and with great planning in projects where cost is a concern, as is the case in most public and private projects.

Reducing the amount of material used in a construction project is a primary way to cut costs. For an on-site construction, materials are procured and delivered to site where they are staged and phased for installation. Most times, the building materials are overordered to make sure adequate quantities for the tasks are obtained. Furthermore, material and products are stored onsite, in comparison to OSM, where the subassemblies are delivered for installation on site only when they are needed. Staging and maneuvering a site can take up a significant amount of a contractor's time, increasing the overall project costs. With OSM, materials are delivered when needed, requiring less on site installation materials resulting to reduced time and overhead (Smith 2010).

Prefabrication may also incur additional costs such as increased transportation costs and craneage for larger elements. Although OSM necessitates larger trucks for transportation, of which many are expensive and requiring extensive labour coordination, transportation for onsite construction typically does not take into account daily trips done in personally owned vehicles to deliver forgotten or overlooked materials so as to have a job completed. These transportation costs are often folded into the larger bid for a subcontractor in an onsite delivery. OSM may also necessitate larger cranes, raising construction costs. Contrary, the number of lifts required by a crane with an OSM building is less than with an on-site construction (Smith 2010).

Extra costs such as factory overhead, may raise bids over their on-site equivalents. Either using OSM or not, the main contractor pays for majority of the set-up costs related to on-site power, toilets, firstaid and job trailers in some instances. As a result, without accounting for the manufacturer's overhead against an on-site sub-contractor, OSM cost can be high deceptively. Often, this is compensated for in terms of time savings and improvement in quality. Products are rarely produced better, faster, and cheaper. Although often times offsite methods can be less expensive, this is not always the case with regards to materials (Smith 2010).

OSM also emphasizes the importance of balancing capital and lifecycle costs. Capital costs, also known as initial costs, are classified as fixed or variable. Site acquisition, permits, and impact fees are examples of fixed costs. Soft costs like preconstruction design fees and hard costs associated with the actual physical construction are examples of variable costs. Capital costs can influence if a project is constructed on-site or off-site. Even though a building could be constructed at a lower cost initially, the payback could not be as favorable in long-term. OSM should be viewed as a lifecycle investment, one that may be more expensive at first but provides better value in the long run (Smith 2010).

Soft costs associated with prefabrication design may be higher in distinct one-off construction projects. With OSM, consultants such as structural and mechanical engineers, and manufacturers are frequently involved in early design stages, escalating upfront design costs. Their participation should not exceed the system's capacity to recover the costs (Smith 2010).

Gibb (1999) notes when assessing offsite fabrication costs against onsite construction costs, the following items should be reviewed:

Possible additional costs

i. Actual costs of manufacturing facility.
ii. Additional costs associated with large capacity transport.
iii. Additional costs resulting from increased site craneage capacity.

Possible cost savings

i. Productivity costs savings made from OSF.
ii. Onsite costs savings due to lessened construction duration.
iii. Onsite costs savings due to lessened onsite work.
iv. Onsite costs savings from reduced construction workers engaged.

v. Cost savings from less transport.
vi. Cost savings from more efficient site craneage use.
vii. Cost savings resulting from reduced unplanned onsite remedial works.
viii. Changes in projected cash flow.

Ludeman (2008) notes that although OSM manufacturers for construction hold that OSM is less expensive due to significant time and labour savings, the hidden costs may be as elaborated below:

i. Overhead; fabrication facilities engage fulltime workers and incur facility costs like purchasing and maintaining equipment, renting the space, and paying utilities monthly.
ii. Profit; OSM manufacturers, have to make a payback. They may charge as much as or more than a general contractor for the same scope of works and savings made from the efficiencies in time and labour may not be passed down to the clients. Also, with the aim of covering the overhead costs.
iii. Transportation; OSM transport costs are more due to the chunking of elements, which are frequently transported with more airspace than closely packed materials for on-site construction.
iv. Setting; while weight is often not a concern as much, craning OSM building elements into position can be mind-boggling and necessitates skilled labourers or dedicated teams to lead and set the building elements on the site.
v. Design fees; since OSM necessitates much more coordination with the construction teams and fabrication teams, the designers could charge more for the increased engagement.

2.2.5.2 The Principle of Schedule/Time

Gibb (1999) notes that a reduction in onsite construction duration is arguably the greatest productivity benefit of OSF. This is accomplished through the overlapping of offsite and onsite construction activities that would have been otherwise performed sequentially by use of traditional methods. Smith (2010) notes that the capacity to manufacture offsite as work on-site is concurrently ongoing results in time savings on prefabricated building projects. Because precast foundations are hardly ever used. Foundations and other related site works can be built on-site while the structure, enclosure, services, and interiors are prefabricated offsite. As traditional construction on-site is a linear process whereby sub-contractors wait for the previous subcontractor to finish their work, teams can work simultaneously in a factory allowing whole parts of the building be constructed by several subcontractors in a given time. Moreover, several fabricators may be producing subassemblies that are brought and assembled together on-site.

Smith (2010) notes that to have simultaneous factory and onsite work taking place, delivery need to be front loaded, which means that most of the planning happens prior to construction using an integrated process. OSM decisions are made early in the project for time savings to be realised.

OSM allows for more predictability in completion because of the capacity to purchase materials and processes quicker, as well as the fact that OSM takes place in an environment that is controlled in which weather has no effect on labour force. Interests on financing are compounded at higher rates making longer construction durations more costly. Public buildings may have more schedule flexibility, vis-a-vis daily income-generating businesses in which the ability to commission as per the schedule determines their business viability. Businesses opening at specific times of the year, targeting a retail season, schools opening for a new term, and hospitals requiring new vacant beds, are all examples of building projects that are constricted by time (Smith 2010).

Gibb (1999) notes that the project team members will almost often benefit from a reduction in project duration. The client will receive the facility sooner, often meaning an earlier start to manufacturing or renting of a commercial property, leading to earlier generation of income. Some clients, particularly retail clients, see this as a significant benefit, impacting the overall project feasibility.

2.2.5.3 The Principle of Labour and Productivity

Smith (2010) discusses prefabrication impacts on labour productivity and notes that productivity is a measure of labour efficiency. With OSF, technical changes such as factory machinery, material science evolutions, and BIM and CNC digital revolutions have all had positive impact on labour productivity in construction. Goodrum, Zhai and Yasin (2008) published a study assessing these improvements and productivity as a result of prefabrication functions. Advances in machinery, physical manufacturing tools and prefabrication technology, or, in a nutshell, equipment technology, have impacted labour productivity in the following ways:

i. Increased output by amplifyinghuman energy.
ii. Greater control, accuracy and quality.
iii. Increased flexibility in manipulating manufacturing.
iv. Increased processing of information through the use of CNC tools.
v. Better ergonomics for less fatigue and greater safety.

Smith (2010) further notes that technological advances made in building materials have increased productivity by:

i. Reducing the materials mass.
ii. Increase in material strength.
iii. Material curing and cooling time.
iv. Installation adaptability in varying weather conditions.
v. Offsite material customisation.

In his findings, Smith (2010) established that using lighter materials increased labor productivity by 30% for a similar activity. Furthermore, labor productivity increased when construction tasks were carried out with materials easier to install. Material and manufacturing technology cannot solely determine productivity, although, the report indicates a significant increase in productivity in projects which include material advances in OSM, and equipment and information technologies.

Gibb (1999) notes that the manufacturing environment allows for increases in productivity of tasks that would be difficult or impossible to attain on site. Even the construction sites that are most efficiently organised require workers gather their tools and move to other parts of the site to complete their tasks. It is usually challenging to deliver all of the required materials to the worksite. During meal breaks, operators often take some time moving around the site or getting more materials. Effective communication is difficult to sustain and good supervision is nearly impossible to attain. Operations in a prefab environment can be re-scheduled or re-sequenced, workstations can be modified, productivity inducements can be easily operated and so on. The prefab factory's location often indicates relatively stable workforce, which is easier to train and more likely to productively work.

Worker safety is raised by the state of conditioned, dry interior environment of the prefab factory. On-site construction exposes labourers to harsh weather conditions and dangerous positions near roads, hazardous protrusions and such, and involves the labourers to make long commutes. Projects outside of major cities necessitate on-site construction labourers to live in temporary structures and go home on weekends. OSM allows for short commutes reducing cost and risk of the labourers' long distances commutes as they are already fatigued from working long hours (Smith 2010).

2.2.5.4 The Principle of Scope

Gibb (1999) notes that the "scope of a project refers to its breadth, size, complexity, and the involvement of individuals and teams required to complete the undertaking". This includes those involved in the actual construction, and the whole design and delivery teams. Increases in design and construction scope are to be expected arising from increased coordination, integration, and the requirements of early OSM decision making prior to the start of construction. In prefabrication, integration happens at the physical and organisational levels.

Smith (2010) notes that integration necessitates design teams collaborate in their efforts and contractors participate in the building planning process in the course of design. For OSM to be used effectively with regards to this, it has to be contextually suitable, and having the contractor understand and inform the design team about general construction concepts ahead of time. Consequently, it is necessary to establish an intent of design, manifested by the construction drawings and documents on which the building is to be built, as well as an intent of construction (a concept for manufacture, delivery and installation), which is integrated with the project's design. Consequently, there is an integration of teams in the decision making, and potentially an integration of prefabrication of products or outputs that indicate a more integrated building system.

OSM over on-site methods enables contractors to more effectively check the integration of SCM through digital tools use to increase quality, reduce cost, and control the greenness of materials being applied. SCM is “the management of a network of interconnected businesses involved in the ultimate provision of product and service packages required by end customers. SCM encompasses all movement and storage of raw materials, work-in-process inventory, and finished goods from the sourcing to usage” (Harland 1996).

Smith (2010) notes that productivity increases with OSM scope, although not at the expense of increased communication before and during construction. On-site errors in scope and schedule can result in weeks, if not months, of delays. A factory setback can be retooled by re-aligning and re-scheduling. The factory environment controlled more yet flexible. Bringing work into the factory decreases the number of change orders.

When design changes are required as not all issues are identified during the design stage, a factory labour force is more adaptable and frequently does not require another sub-contractor when the changes happen. Frequently, the cost of the changes can be taken in within the factory operations as it is offset by other efficiencies. The inflexibility of on-site construction exposes the project team's vulnerabilities to financial agony and may result in a variation in the project's scope entirely (Smith 2010).

In contrast, small, quick adaptations on-site can usually be made faster than with OSM elements. For instance, if a building element is transported to site 95% complete and a design change needs to be done based on on-site as-built foundation, this cannot be easily managed on-site, but rather the building element has to be transported back for readjustment. These fixes are adaptable with on-site methods. Therefore, there is a great deal of flexibility if the building element is still in the factory before transportation, but if transported, it is completely the opposite (Smith 2010).

2.2.5.5 The Principle of Quality

Gibb (1999) notes that a factory setting is better suited to manufacturing products of high quality, though this does not imply that all work done on site is going to be low-quality, or that all prefabrication is going to be of higher quality, since there are other considerations.

Smith (2010) notes that quality is twofold: quality of production and that of design, which is frequently connected with architect's work. Both have to be valued equally for OSM to succeed. These principles appear to be opposites. As production quality improves, construction becomes more standardized, blan, and uniform, whereas a highly individualised design implies a lack of manufacturing efficiency. Although, OSM is not synonymous with standardisation, it is only as good as the expectations on it from a design viewpoint. It takes the creative ability of architects, engineers, fabricators, and contractors to imagine a way of increasing design quality and production quality to the collective gain of both. This is an OSM architecture challenge.

Construction on-site is still an artisanal tradition. Whilst other sectors rely on automated technology and precise manufacturing methods, building construction depends on trained labourers. OSM increases product accuracy and hence provide for better control over the final product. As a result, manufacturing warranties are more extended. OSM manufacturer can guarantee quality and workmanship of the products as well as factory replacement components. A higher level of guarantee may be enforced if OSM is done and installed by the same manufacturer (Smith 2010).

Manufactured components might have reduced dimensional tolerance alongside improved precision. Tolerances are relatively simpler to manage in OSM. The tolerances include how precise an element is to the design, and how it integrates with other on-site built elements such as foundations. OSM allows for a product that is more probable on budget and time, alongside improved precision assuring more predictability. This might be through standardized elements that have already been successful proven, or tested through multiple prototypes before manufacturing in large quantities. On-site construction can also be of high quality, only that OSM achieves this at a cheaper cost (Smith 2010).

Gibb (1999) notes that majority of clients want assurance of their projects meeting their business goals, be executed to the desired quality, within the budget and on schedule/time. While predictability may not always result to a reduced project duration, less costs, or higher quality, it allows the project team focus on other issues with confidence that OSM elements have been manufactured to a predictable quality.

2.2.5.6 The Principle of Risk

Gibb (1999) notes that construction sites are hazardous. OSM reduces the quantity of onsite work, reducing exposure to hazards. Often OSM reduces, or entirely eliminates, the need for onsite work at hazardous heights. Moreover, OSM necessitates a more deliberate approach to the construction management, as delivery and installation has to be scheduled prior, allowing necessary risk evaluation and assessment to be done.

Risk is unavoidable in the undertaking of attaining design and manufacturing quality. Building elements and systems that have previously been used in a building construction project are widely accepted, tested and verified. Developers that are risk-averse avoid OSM of building elements that are not available in the market as they do not wish to incur liability of unique untested building elements. Other developers see the liability as a chance to distinguish them. Designers also risk when undertaking a project using OSM. Fabricators could be most willing to take up such projects due to their understanding of the requirements to complete the works and stand to profit financially. All stakeholders take risk on projects that utilise OSM to achieve a distinctive project, or use OSM for its capacity to manage cost and time, until the prefabrication has been demonstrated to surpass on-site approaches (Smith 2010).

Variations from the standard poses financial risk for clients, designers and contractors. Notwithstanding, numerous OSM building elements are well proven, and the lack of willingness has less to do with risk, but more with not wanting the trouble or feeling indifferent about the final product. If a lending financial institution is not familiar with OSM, stakeholders would want to look into other institutions more familiar to lending for OSM. Some OSM prefabricators may finance projects by themselves, allowing them cover construction costs with downpayments (Smith 2010).

In the future, extended producer responsibility (EPR) could solve building construction financing. EPR is the concept of having prefabricators retain responsibility for their building products and components in the secondary market. EPR entails stewardship for the building's durability performance over its design lifetime (Schwartz and Guttuso 2002). For prefabricated elements, EPR proposes leasing. The leaser establishes terms with an agent by paying a monthly rate, which is often the product's depreciation value during the lease time. The provider maintains the system, and then updates it for a new lease(r) when the lease expires. This is widely used in portable modular construction, but not in several other construction areas. Smith (2010) further notes that banks are unfamiliar currently with this model for financing construction projects. This is a crucial barrier that must be controlled for other prefabrication financing to be feasible.

2.2.5.7 The Principle of Reusability and Relocatability

Gibb (1999) notes that OSM units can be designed to be re-used or re-located. This is made easier by the fact that the structure is constructed from prefab sub-assemblies. The ability to move structures enables clients respond to changing market needs such as moving retail units to a more profitable location, utilising sites that are only available short-term, and providing short-term accommodation such as at big sporting events, or in emergency response situations. A typical modern example is a complete modular building. One of the most important aspects in relocatability of such structures is the speed of onsite tasks. Although, in practice, relocatability is hardly used as most modular buildings stay in their initial locations all through their life.

2.2.5.8 The Concept of Research and Development

Smith (2010) notes that the concept of research and development (R&D) is linked to quality and risk. On-site construction projects rarely have the capacity for R&D. Because of process of design-bid-build, contractors try finding the lowest regular factor in order to complete a building construction project. This includes looking for gaps in contract documents, determining where costs can be lowered from the start of construction or making a inaccurate bid to secure the works and then thinking of delivery later. Most on-site contractors acknowledge that they must provide an informed guess to a part of the bid because each project presents unique uncharted territory with regards to labour, material and time/schedule.

Offsite fabricators can be an essential part to the tender process or work with design and construction teams early in a design-assist delivery to ascertain cost estimates and make the design be within a constructible and affordable balance, thanks to prefab architecture. Unique or specialized parts of a building that need OSM may appear riskier to the client and contractor, but attempting to achieve these specialized systems on-site adds more risk significantly. Even in projects with low risk, attempting to achieve higher quality in the factory through more predictable methods is a lower risk enterprise (Smith 2010).

2.2.6 OSM and the Economies of Scale

Rukwaro (2019) notes that the economics offered by a particular technique of industrial production are a function of the scale application. When the costs of basic materials are high, and the investment required in mechanical plant, factory space, etc., is relatively low (as is often true with timber), a fairly high level of industrialization may be profitable on a small scale. At the opposite extreme, where large capital investment is called for (as with some modern techniques for the highly automated and rapid production of large concrete units), an assurance of large-scale application over a considerable period is essential.

Similarly, a large scale of production will justify a much more intensive design study than a single relatively small contract. If the scale is large enough, considerable refinement of the design may be possible as a result of prototype testing and development. To some degree the economies offered by large-scale production can be extended to the smaller single contract by the informal process of carrying over experience from one job to another and the use of existing resources for mechanized production and erection. System building and component building are two more formalized alternatives to this informal process. Neither is tied to any particular form of construction. Only component building is necessarily tied to prefabrication. The system approach can equally well be applied to mechanized in-situ construction, although most existing systems do, in fact, involve extensive pre-fabrication to reduce site work to a minimum, and the emphasis here is on those that do.

2.2.7 OSM and Sustainability

Golubchikov and Badyina (2012) note that new construction technologies play a significant role in bolstering the construction industry, but they must adhere to the sustainability triple bottom line of society, economics and the environment. Anderson and Anderson (2006) note that a thoughtfully integrated construction ecology can logically lead to important costs reductions in energy and transport; reductions in materials waste and redundant warehousing; the re-usability and re-cyclability of building components; and great savings on the job site in time, frustration, injury and redundancy.

Sustainability has become comparable to minimizing environmental encroachment and degradation. Sustainability is defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. This significantly expands the definition of sustainability. A significant aspect in sustainable construction practices include environmental impact of buildings over their lifecycle, and economic, social and cultural considerations. The architecture, engineering and construction industry must evaluate sustainability in terms of natural and human capital. To be truly resilient, a system must rely on both to succeed (Hawken, Lovins and Lovins 2010).

Smith (2010) notes that OSM may be used to improve the construction sustainability from the point of view of the facility’s total lifecycle, particularly when it comes to demolition or reuse. In the future, OSM’s ability to deliver buildings, which respond to time, change, and reuse/recycle could be its most significant advantage towards total lifecycle sustainability. Smith (2010) notes that architects are primary actors in deciding the materials used in buildings and thus play a primary role in influencing the extraction, recycling and processing of specific materials, the manufacture and assembly of components, and the construction of buildings. Buildings designed for a specific lifetime use prefabrication strategies: designed for disassembly; designed for re-use; designed for temporality; and designed for change.

A building’s energy consumption is broadly divided into two: i) construction; the energy embodied in materials and processes of putting up a new structure or renovation; and ii) operation; the energy and maintenance needed to operate a building all through its lifecycle. More than 90 percent of a building's total lifecycle energy is contributed by operational energy, or energy used after occupancy. As a result, one might dismiss the importance of initial energy, believing that project teams need to concentrate solely on operational energy that results in a higher performing building at the expense of embodied energy. Nonetheless, as buildings become more net zero efficient, the issue of initial energy will become an increasingly significant area of practice and research. OSM holds great promise for initial and operational energy impacts because it allows for less material to be used during initial construction, more control on materials and their embodied energy, and is much more controlled during construction, enabling the building to perform better during its operational life. However, of the two, OSM has more evident direct relevance to construction energy savings (Smith 2010).

On sustainable sites, offsite manufacturing techniques limit site disturbance and keep affected areas to within the space adjacent to the building footprint, as the process of construction can be planned carefully to counter site disturbances. Regarding water efficiency, conservation, and reuse, there is no major benefit of using OSM over onsite construction in the LEED credits (Smith 2010).

In their study investigating the sustainability level in offsite construction, Moradibistouni, Vale and Isaacs (2019), found the primary findings revealed that OSM is more sustainable than onsite traditional methods with regards to both water consumption and waste generation. However, the differences between OSM and onsite traditional methods are minimal regarding energy consumption and environmental pollution. This analysis demonstrates that comparing prefabrication to other methods of construction without taking into account other aspects affecting construction sustainability, like material selection and approaches to design, is impossible.

Gibb (1999) notes that the use of prefabrication has several environmental advantages, which include: i) less onsite work, which is less sensitive environmentally; ii) less wastage of material; iii) less noise, dust, etc.; iv) better controls on atmospheric pollution; v) usually less energy used in transport and onsite works; and vi) the recycling of materials and supplies in an offsite manufacturing environment is much easier.

Acioly *et al.* (2012) details a multi-scale framework for policies on sustainable housing under the four-dimensional sustainability model of economic, social, cultural and environmental considerations. This is captured in detail Appendix 01, however, Table 2.2.7:1 is author modified to capture the framework at the micro level.

Table 2.2.7:1 A micro level multiscale framework for policies on sustainable housing.

Sustainability Dimension	Micro Level (Neighborhood, Household)
Environmental dimension	Ensuring energy efficiency, microgeneration, water and resource efficiency. Green design, using sustainable local construction and materials. Sanitation, preventing hazardous and polluting materials. Affordable use of resources. Improving resilience and adaptation of built forms.
Social dimension	Empowering people and ensuring public participation. Ensuring health, safety, well-being in the built forms. Creating a sense of community, 'sense of place' and identity. Meeting specific needs and wants in the built forms (including those related to gender, age and health). Providing access to infrastructure and public spaces.
Cultural dimension	Culturally responsive built forms in planning and design. Improving aesthetics, diversity and cultural sophistication of the built forms. Helping community creativity (i.e. via amenities; affordable sporting, cultural and entertainment facilities. Assisting people's transition from rural and slums areas to decent built forms.
Economic dimension	Ensuring affordability for different social groups. Providing adequate works to raise labour productivity; ensuring prefabrication is integrated with employment. Supporting domestic economic activities and enterprise. Promoting petty landlordism and self-help housing. Improving built forms management and maintenance. Strengthening resilience and future proofing of the built forms.

Source: Acioly et al. (2012); Author modified (2021).

2.2.8 Offsite Vs Onsite Manufacturing Comparison

Smith (2010) notes that offsite manufacturing is not a win-win solution, as OSM has to be implemented in relation to a specific location and time in a construction project. Tables 2.2.8:1-3 are an on-site and offsite production comparison based on the offsite manufacturing principles discussed. This is intended to assist architects and builders in assessing the benefits and drawbacks to consider when planning or implementing offsite manufacturing in an ongoing project.

Table 2.2.8:1 Cost and schedule/time comparison of offsite vs onsite.

Principles	Offsite	Onsite
Cost		
Financing	Interest reduced on shortened schedule, even draws, and leasing options, alternative methods might be seen as risky for lenders	Traditional construction loan/ mortgage financing, lending freezes make construction actuation difficult
Administration	Administrator overhead reductions	Bureaucratic layers for decision making
Insurances	Lower contingency costs	Higher contingency costs
Transportation	Two stage delivery shop and site	Raw material delivery only
Change orders	Extra cost and delay	Accommodated changes
Overhead	Larger shop overhead – people, equipment, space, utilities	Overhead is absorbed into construction budget
Schedule	Duration reductions recapture investment earlier	Schedule overruns are common increasing overall budget
Material	Less scaffolding, formwork, and shuttering	Increased scaffolding, formwork and shuttering
Craning	Costly heavy duty cranes for setting	No cranes for small projects, large stationary crane for larger
Initial cost	Higher investment in product	Lower initial cost for normative projects
Lifecycle cost	Greater return on investment (ROI) over long term	Greater maintenance requirement
Profit	Subcontractor overhead costs project more, savings from scope, material may not be passed onto customer	Overhead fees are more transparent to owner
Design fees	Higher due to coordination requirement	Standard fees
Lean	Reduce time waste increase value	Waste laden process
Productivity	Full 8 hours of work, sophisticated machines, digital tools available	Productivity increases difficult
Economy	When strong plenty of residential work, but less commercial, when weak, less residential and more commercial	Residential and commercial ebb-and-flow with markets
Schedule/Time		
Duration	Finish date met 50% reductions	Schedule overruns are common
Scope coordination	Extra coordination needed between site and plan	More time for coordination and opportunity to adjust dimensions
Schedule reliability	Longer lead time, reduced erection time, reliable duration	Shorter lead time, longer construction and less reliable
Permitting	Streamlined in familiar jurisdictions opposite in unfamiliar	Dependent on jurisdiction
Weather	Sun always shines	Delays due to weather are common
Work flow	Concurrent scheduling	Linear process
Subcontractors	Fewer conflicts better sequencing	Simultaneous trade crowding difficult
Supply chain management	Coordinated and streamlined	Uncoordinated and wasteful

Source: Smith (2010).

Table 2.2.8:2 Labour and scope comparison of offsite vs onsite.

Principles	Offsite	Onsite
Labour		
Local labour	Less local labour needed	Local labour needed
Working conditions	Improved working conditions and more stable job market	Variable working conditions and more sporadic job market
Skill level	Craft and technical skills needed	Craft and problem skills are elevated
Subcontractors	Fewer conflicts better sequencing	
Unskilled labour	Supervision of labour, quality control process	Unsupervised labour leads to portions of project being reconstructed
Labour comfort	Ergonomics increased	Physically difficult
Safety	Reduced exposure to accident	Accident prone job site
Health	Better life style and mental health	More opportunity for variety in work
Skilled labour	Less chance for skill development	More chances for skill development
Commute	Factory near house – full 8 hour days and no out of town travel	Out of town projects require commute times
Productivity	Full 8 hours of work, sophisticated machines, digital tools available	Less productive use of labour force
Union	Declining due to immigrant population making less room for offsite	Accommodates variety of labour types
Scope		
Supply Chain Management	Long term supply chains for materials established	Supplies restricted to project-based purchases
Coordination	Extra coordination needed between site and plan	More time for coordination and opportunity to adjust dimensions
Flexibility	Changes often cannot easily be made in field	Limited adjustment can be made easily in the field
Impact of changes	Less accommodation	More accommodation
Maintenance	Reduced maintenance and operations	Higher maintenance and operations
Transportation	Two stage delivery shop and site	Raw material delivery only
Flexibility	Changes not made in field	Adjustments made in field
Design	Requires higher level of detailing for assembly, only 50% with bridging documents	Design intention communicated only
Production	Predictable output, mockup and prototype required	Difficult to anticipate, depends on skill level of construction crew
Regulatory	3rd party verifiers	Local agency to inspect
Predictably	Increase expected outcome	Less predictable delivery
Staging	Less material on site, but must be coordinated well	Staging is logistically difficult
Accessibility	Specialized companies, takes research and work	Smaller construction companies

Source: Smith (2010).

Table 2.2.8:3 Quality and risk comparison of offsite vs onsite.

Principles	Offsite	Onsite
Quality		
Reliability	More reliable quality can be achieved in shorter amount of time	Less reliable (depending on the site conditions and skill level of labour)
Coordination	Integrated effort between factory and site	Flexible coordination and adjustments
Design	Integrated design and construction process	Separation of design and construction
Production	Predictable output, mockup and prototype required	Difficult to anticipate, depends on skill level of construction crew
Regulatory	3rd party verifiers with industry knowledge	Local jurisdiction with varied experience
Predictably	Increase expected outcome	Unpredictable quality
Innovation	R&D capacity and control	No research and development time or resources
Design flexibility	More restricted	More freedom
Equipment	Easier access	Equipment to and from site
Environment	Lower waste, air and water pollution, dust and noise, and overall energy costs	Difficult to manage waste and energy in construction
Handling	Potential for damage during handling	Smaller elements easier to handle
Joining	Fewer joints, but difficult to detail	More joints, more potential for failure
Tolerances	Great capacity, not forgiveness in module on site	Forgiveness with details constructed on site
Fit	Fewer points for water and air infiltration	More locations for infiltration
Quality of materials	Quality control in SCM sourcing	Contingent upon source
Warranty	Opportunity for comprehensive warranty of products from one supplier	Dedicated to each system supplier
Risk		
Cost	Overall higher cost potential, more predictable	Standard bidding process brings waste, cost is unpredictable
Handling	Transit damage potential, cumbersome large scale unit install	Multiple trips, smaller pieces for easier per install handling
Public perception	Negative	NA
Innovative	Greater innovation possible	More difficult to achieve innovation complexity
Safety to labour force	Safe indoor labour conditions	Statistically more dangerous
Tolerances	Discrepancy between onsite and offsite elements present problems, element tighter tolerances	Tolerances can be accommodated easily in onsite installation
Fit	If not fit, changing size of element is costly	Onsite accommodation to fitting issues resolved without added cost
Quality	When increased, risk goes down	Higher exposure to risk due to material and joint failure

Source: Smith (2010).

General categories can be derived from this exhaustive list of prefabrication parameters. To begin with, productivity is the main factor in any discourse of offsite versus on-site methods. This is due to improved collaboration among project participants such as designers (architects and engineers), clients, contractors, and subcontractors. Traditional on-site construction delivery is often not logical or efficient. Construction, contrary to other manufacturing industries, is fragmented, which causes waste in building delivery, from the design to SCM and procurement. This is due, in large part, to the industry's separate contract structure, which places designers and contractors, design and manufacturing on opposing sides. Integrated processes enable construction delivery to be flattened while increasing productivity. Prefabrication and integration are collateral principles (Smith 2010).

2.2.9 When Should OSM be Used?

Tatum, Vanegas and Williams (1986) note that to make the best use of the offsite fabrication techniques, it is essential to establish a project-wide strategy on offsite manufacturing early on. OSM introduces numerous changes to projects and places new demands on management. These methods can change project organization, planning and monitoring, necessitate more coordination and affect project outcomes.

Smith and Quale (2017) note that there is no single best universal system in the world in their quest to find out which building system would be the most relevant for a specific project. The answer should be governed by the given context: the needs (program) and resources (the four M’s: materials, machinery, manpower and money).

Smith and Quale (2017) further note that selecting the relevant building system is an optimization operation that should take four major factors into account: the performance criteria set forward to meet the objectives of the project; a comparative analysis of the context against the advantages and limitations of the various types of industrialised building system currently or prospectively available; the presence or the set-up of an organizational structure maintaining the continuity required to amortize the operations; and the presence or the development of technologies capable of simplifying the production at the factory and the installation at the site.

Smith (2016) notes that the intent here is not to imply that offsite in general, or any particular offsite system, are appropriate solutions to building problems. OSM has outperformed on some building types, with specific building teams, and in specific locations. These guidelines are not intended to be definitive, but rather to suggest factors to consider when deciding whether or not to work with OSM.

Blismas (2007) notes that prefabrication supporters must be more vigilant if OSM is to be preferred over traditional on-site methods. Offsite manufacturing principles as discussed such as cost, schedule/time, labour, scope, quality and risk have to be researched in theory and practice so that constituents of construction industry have the information, knowledge, contract structure and capital to enact these technologies and processes sooner.

Pan, Gibb and Dainty (2012) note that the following strategies need to be considered in using offsite manufacturing: establish overall project offsite strategy; outline planning stages and detail design preparation; completion of coordinated design and preparation for manufacture (ensures OSM integration into outline and detailed design preparations); construction completion and post-construction care and reviews.

2.2.10 Implications of OSM

Parameters that need to be considered in the use of OSM techniques

In order to optimise offsite fabrication, Gibb (1999) notes that a strategy that is project-wide has to be agreed upon and implemented early on in the project. At this early stage, acquiring applicable information from manufacturers and installers will be required. These implications of offsite manufacturing include:

i. Procurement strategy; numerous methods of procurement have been successful in attaining this such as; strategic partnering, nominated suppliers, two-stage tendering, management forms of contract, design and build, and design and manage.
ii. Interface management; interfaces exist between each component or element of a building, and between each of the organisations engaged in the construction process. Effective construction management will make sure that critical matters are assessed from an overall project viewpoint and will dwell on managing the interfaces between elements and organisations.

iii. Design implications; dimensional coordination and module size; effective design and site control of tolerances; building regulations and statutory approvals (as in some regions, offsite fabricated buildings, facilities and structures are treated differently in the statutory regulations); checking redundancy of structure and increased building size (as some offsite fabricated volumetric units, or some modular building systems have structural redundancy); and consider design aesthetics & innovation. All these aspects need to be properly considered at design stage.

iv. Information technology; IT advances have had particular effect on offsite manufacturing in the fields of virtual reality and three dimensional CAD with object-oriented databases; digitally controlled fabrication and manufacturing machinery; and decision support software. This has significantly increased productivity.

v. Pre-installation trial assemblies or prototypes are an integral part of effective offsite fabrication. Fabricators in other industries would not advance to production without prototypes or trial assemblies. In the cases where standard prefabricated or pre-assembled units are used, the prototyping has already been done, and the units are tried and tested, thus increasing predictability of fit and performance.

vi. Transporting and installing offsite manufactured building elements varies greatly depending on the character of the elements themselves. A completed element has to be lifted at the factory, transported to and lifted on site, in most cases transported through the site, set in place and levelled and connected structurally to adjacent units, with building services, to create a waterproof seal. Design considerations, access within the building and craneage need to be well factored.

vii. Optimising and organising onsite work, including maintenance requirements; some onsite work will always be required, in preparation for the offsite fabricated elements or following their installation. Such instances include provision of maintenance access for example building services provisions.

viii. Retraining and reskilling; to realize the full advantages from offsite manufacturing, team members may have to be retrained or reskilled. Furthermore, once the project team is formed, it is imperative to ensure that all stakeholders understand and support the project's OSM strategy.

2.2.11 Constraints to the Adoption of OSM Techniques

Nawi, Lee and Nor (2011) identify some of the factors that constrain the adoption of OSM, which primarily revolves around cost, skills and knowledge, project delivery and supply chains, customer and professional perceptions, and lack of government policy, incentives, and promotion.

Blismas (2007) conducted a survey on professionals in construction in Australia to assess lack of penetration of OSM in the market, with the findings indicating the following constraints to offsite method adoption in the industry:

i. Lack of knowledge by clients and professionals within the industry including designers and contractors.
ii. Lack of information on proven precedentsdemonstrate a cost-benefit ratio.
iii. Outdated design and construction culture that encourages discipline separation.
iv. Lack of availability of processes and programs (contracts).

Constraints to the implementation of IBS can also be considered for OSM. Saggaff (2017) notes that the following are some of the drawbacks and delays associated with OSM implementation:

i. OSM is not a popular choice among consultants and developers due to a lack of knowledge and understanding of the OSM system's performance.
ii. Construction industry players' mindsets must be changed to recognize that OSM is far superior to traditional on-site construction in the long run.
iii. Inadequate push factors from governments and policymakers, such as the public works department and local governments.
iv. Inadequate technical knowledge from manufacturing to construction.
v. Volume and initial production costs issues must also be addressed in the supply chain.

Aside from these shortcomings, the way forward for implementing OSM use is very much critical in order to maximize the benefits of OSM.

Blismas (2007) notes that the United States faces unique prefabrication constraints due to its unique construction context. Eastman and colleagues speculate that the lack of adoption of prefabrication in the United States is due to labour issues in construction such as:

i. Construction companies are small generally, with fewer than 5 people in 65% of firms making investment in technology hard and changing operations to rely on offsite manufacturers difficult (changing delivery methods appears to be easier because there are no layers of bureaucracy, but smaller firms are a result of smaller construction projects that do not have the budget to invest in new prefabrication and automation techniques).
ii. Labour productivity has decreased proportionally as wages and benefits have stagnated, union participation reduced, and the use of immigrant labourers increased, reducing the need for labour saving innovations such as OSF.

One of the objectives of this study seeks to identify the parameters that influence negatively the decision to not use OSM concrete building elements in Nairobi. The data findings and analysis will be discussed in chapter four.

2.2.12 Strategies to Increase the Adoption of OSM Techniques

Having known and understood factors that impede the adoption of OSM, they could then be looked at in the view of establishing strategies to counter them in order to influence positively the adoption of offsite manufacturing. Strategies to counter the constraints listed under item 2.2.11 include:

i. Taxation subsidies on materials. Gbadebo (2014) notes that to encourage industrial production, the government should provide financial incentives through taxation, effective protection, and other relevant fiscal measures and local building materials industries should be given effective protection.
ii. Creating awareness to the public. Gbadebo (2014) notes that dissemination of information to the general public and "leadership by example" is a requirement of the public sector.
iii. Incorporating OSM building techniques content in curriculum of higher learning institutions and establishing building extension centres, specifically geared to bringing OSM building techniques and related services at national and county levels.
iv. Executing some government projects using the techniques as this shows government commitment.
v. Making research and development advancements in developing OSM building techniques.

vi. Retraining and reskilling of labour force.
vii. Reviewing government policy, incentives and promotion.
viii. Reviewing building code and statutory approvals. Blismas (2007) notes that regulatory change will need to develop simultaneously with increasing OSM building techniques use.
ix. Government dissemination of current and less capital intensive OSM building techniques at national and county levels.

One of the objectives of this study seeks to establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi. The data findings and analysis will be discussed in chapter four.

2.3 Conceptual Framework

The conceptual framework section identifies the independent and dependent variables of the study that were used to achieve the main objective of the study to assess the constraints to the adoption of OSM concrete building elements in building construction projects in Nairobi.

Mugenda and Mugenda (1999), cited in Ebole (2005), note that "an independent variable is a variable that a researcher manipulates in order to determine its effect or influence on another. It is a variable whose available categories are designated in advance by the researcher". Typically, these variables are chosen because they are thought to be causal or very important to the specific logical purpose of the research project. "Dependent variables are so named because their results are presumed to depend upon differences in the independent variable. The variation in them is seen as being related to, caused by, or in some way influenced by differences in the independent variable. A dependent variable therefore varies as a function of the independent variable".

The six main independent variables considered in the study are: cost (capital and operational investment); schedule/time (duration of the project); labour and productivity (skilled and unskilled human workforce); scope (extent or breadth of the project); quality (design and construction excellence); and risk (exposure to financial loss). The other independent variable considered is research and development.

The main dependent variable considered in the study is sustainability with these dimensions: environmental dimension; social dimension; cultural dimension; and economic dimension.

Figure 2.3:1 is a diagram illustrating how the independent variables (cost, schedule/time, labour and productivity, scope, quality, and risk) inform the dependent variable (sustainability).

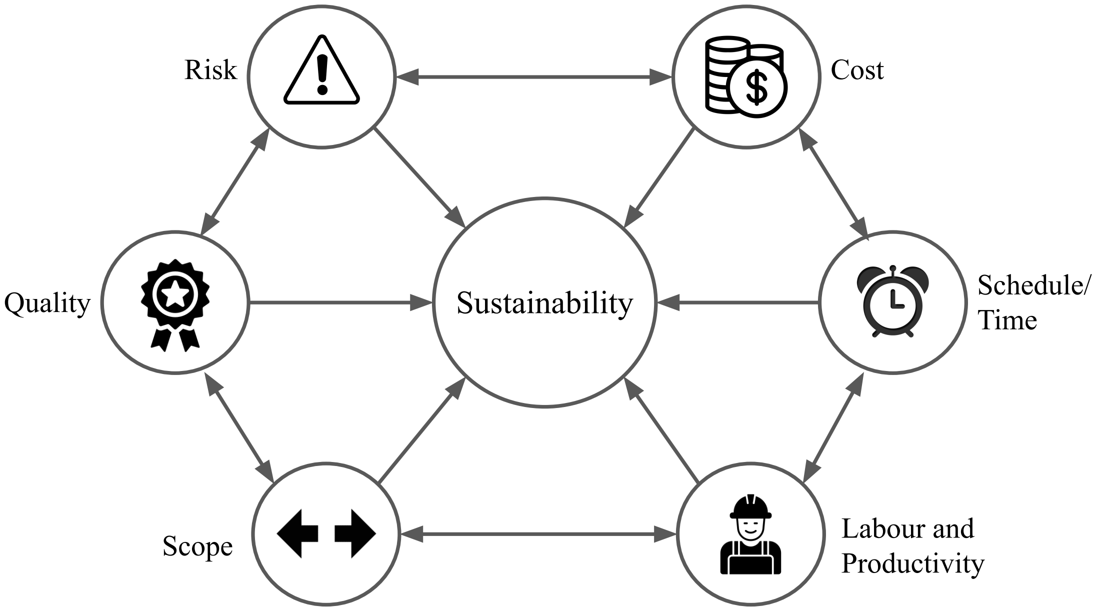


Figure 2.3:1 The independent variables inform the dependent variable.
Source: Author (2021).

2.4 Conceptual Definitions

The conceptual definitions section defines the independent and dependent variables of the study by giving the context of meaning of these variables as applied in the study. Below are the conceptual definitions of the main independent and dependent variables considered in the study.

i. Cost: Smith (2010) notes that cost comprises of three components for which OSM conceptually has solutions; material, labour and time. In principle, if any one of these are reduced, the cost is reduced as well. Other costs associated with OSM are; increased transport costs and craning or setting for large building elements; capital costs (like fabrication facility costs) and lifecycle costs; manufacturing facilities overheads; and upfront design fees costs because OSM requires more coordination with construction and manufacturer teams, hence architects and engineers may charge higher fees for the investment of time.

ii. Schedule/Time: The duration required to complete all stages of construction work and the various processes involved. Gibb (1999) notes that a reduction in onsite construction time is arguably the greatest advantage to productivity of OSM, and this is achieved by the overlapping of offsite and onsite tasks that would otherwise have been done in sequence using traditional on-site methods.

iii. Labour and productivity: Smith (2010) discusses prefabrication impacts on labour productivity and notes that productivity is a measure of efficiency in labour. Technology advances in machinery, physical tools for manufacturing, and OSM technology, or in a nutshell, equipment technology, have all had an impact on labour productivity. Technical knowledge and training are two items to assess.

iv. Scope: Gibb (1999) notes that the scope of a project refers to its breadth, size, complexity, and the involvement of individuals and teams needed to finish the task. This includes those involved in the physical construction, as well as the entire design and construction team. The integration of teams in both the prefabrication decision making & design early on; and construction stages takes place at both the physical and organisational levels.

v. Quality: This relates to the product meeting the teams' specifications and expectations of workmanship. Smith (2010) notes that quality is twofold; quality of production and design quality, frequently associated with the architect's work. In order for OSM to be successful in architecture, both must be valued equally.

vi. Risk: This relates to the exposure to the possibility of incurring losses and hazards at construction sites and other project related risks. Prefabrication associated risks include; financial vulnerability to clients, designers and contractors; unverified fabricators; etc.

vii. Sustainability: Brundtland (1987) defines "sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs". This expands the definition of sustainability. A critical aspect in sustainable construction practices comprises environmental impact of buildings during their lifecycle, economic, social, and cultural considerations (Hawken, Lovins and Lovins 2010). Acioly *et al.* (2012) discusses the four sustainability dimensions as below:

a. Environmental dimension of sustainability in prefabrication relates to; the use of sustainable local construction and materials; the prevention of hazardous and polluting materials; the affordable use of resources; and the improvement of resilience & adaptation of the built forms.
b. Economic dimension of sustainability in prefabrication relates to; ensuring affordability for different social categories; providing sufficient works to raise labour productivity, making sure prefabrication is consolidated with employment; improving built forms management & maintenance; and strengthening resilience and future-proofing of the built forms.
c. Social dimension of sustainability in prefabrication relates to; empowering people and making sure public participation; making sure health, safety & wellbeing in built forms; creating a sense of community, sense of place and identity; meeting certain needs and wants in the built forms (including those related to gender, age and health); and providing access to infrastructure and public spaces.
d. Cultural dimension of sustainability in prefabrication relates to; culturally responsive built forms in planning and design; improving aesthetics, diversity and cultural sophistication of the built forms; and assisting people's transition from rural and slums areas to decent built forms.

2.5 Operational Framework

The operational framework describes the variables, their measures and indicators that will be used in measuring the variables and data collection methods to be used. Table 2.5:1 gives the operational framework that will help achieve the study's main objective to assess the constraints to the adoption of offsite concrete works manufacturing techniques in building construction projects in Nairobi.

Table 2.5:1 Detailed operational framework.

Variable	What to Assess	Measurement Scales
Cost	Initial capital costs; fabrication facility costs. Upfront design fees costs. Material, labour, and time costs. Transportation costs and craneage. Lifecycle costs.	Ordinal scale; Likert scale.
Schedule/Time	Delivery duration. Installation duration; sequencing & overlap.	Ordinal scale; Likert scale.
Labour and Productivity	Skilled/unskilled. Prefabrication technology technical know-how/knowledge. Training. Mindset/perception of productivity efficiency.	Ordinal scale; Likert scale.
Scope	Complexity/extent of project. Integration of design team & construction team. Supply chain management.	Ordinal scale; Likert scale.
Quality, Predictability and Reliability	Workmanship. Achieving specifications issued, by production & products quality and design quality. Durability.	Ordinal scale; Likert scale.
Risk	Quality; unverified fabricators. Financial vulnerability to clients, designers and contractors. Safety and health; exposure to hazards. Extended producer responsibility.	Ordinal scale; Likert scale.
Research and Development	Contractor design-assist delivery. Cost cutting strategies.	Ordinal scale; Likert scale.
Sustainability		
Environmental Dimension	Use of sustainable local materials. Preventing hazardous and polluting materials. Site disturbance.	Ordinal scale; Likert scale.

Social Dimension	Awareness & public participation. Health, safety & wellbeing in the built forms. Jobs created with prefabrication.	Ordinal scale; Likert scale.
Cultural Dimension	Aesthetics; culturally responsive built forms. Promotion of local materials & building techniques.	Ordinal scale; Likert scale.
Economic Dimension	Affordability on construction costs. Post-occupancy operations.	Ordinal scale; Likert scale.

Source: Author (2021).

In that regard, the objectives as set out at the beginning of the study were achieved. Table 2.5:2 below shows the high-level operational framework.

Table 2.5:2 High-level operational framework.

Objectives	**Data Sources**
To identify the types of OSM concrete building elements used in building construction projects in Nairobi.	Observation. Questionnaires. Interviews. Secondary data.
To identify the parameters that influence positively the decision to use OSM concrete building elements in Nairobi.	Questionnaires. Interviews. Secondary data.
To identify the parameters that influence negatively the decision to not use OSM concrete building elements in Nairobi.	Observation. Questionnaires. Interviews. Secondary data.
To establish parameters that need to be considered in the decision to use OSM concrete building elements in Nairobi.	Secondary data. Observation. Questionnaires. Interviews.
To establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.	Secondary data. Observation. Questionnaires. Interviews.

Source: Author (2021).

CHAPTER THREE
RESEARCH METHODS

3.1 Introduction

This study adopted a mix of qualitative and quantitative strategies, seeking to achieve the study objectives, which are to: identify the types of offsite manufacturing (OSM) of concrete building elements used in building construction projects in Nairobi; identify the parameters that influence positively and negatively the use of these OSM concrete building elements; establish parameters that need to be considered in the decision-making to use OSM concrete building elements; and establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

3.2 Research Design

Research design refers to the overall approach taken by the researcher in carrying out a research project or the process that the researcher will follow from the start to end of the study (Syagga 2018). This study used a cross sectional survey research design that integrated both qualitative and quantitative strategies, observations made from sites visited, interviews conducted and questionnaires administered as the primary research approach.

3.3 Data Sources

This research depended on both the primary and secondary data sources. For primary data, observation, interviews and administration of questionnaires were used to collect the information required. The primary data was obtained from: interviewing and administering questionnaires to the built environment stakeholders who in this case were consultants (project managers, architects, structural engineers and quantity surveyors), developers, contractors, manufacturers, and researchers; and also, from visiting sites that were using OSM concrete building elements to make observations.

For secondary data, the author made reference to published and unpublished written literature, journals and internet sourced information on the literature material relevant to the study. The data collected aimed to achieve to the study objectives.

3.4 Sampling Design

3.4.1 Location of Study

The location of the study was Nairobi City County. The author settled to study Nairobi as it is Kenya largest city, with the highest annual growth rates in Africa of 3.81% (UN Habitat 2005). Figure 3.4.1:1 is a map showing Nairobi City County and to a smaller extent the neighbouring counties of Machakos, Kajiado and Kiambu.

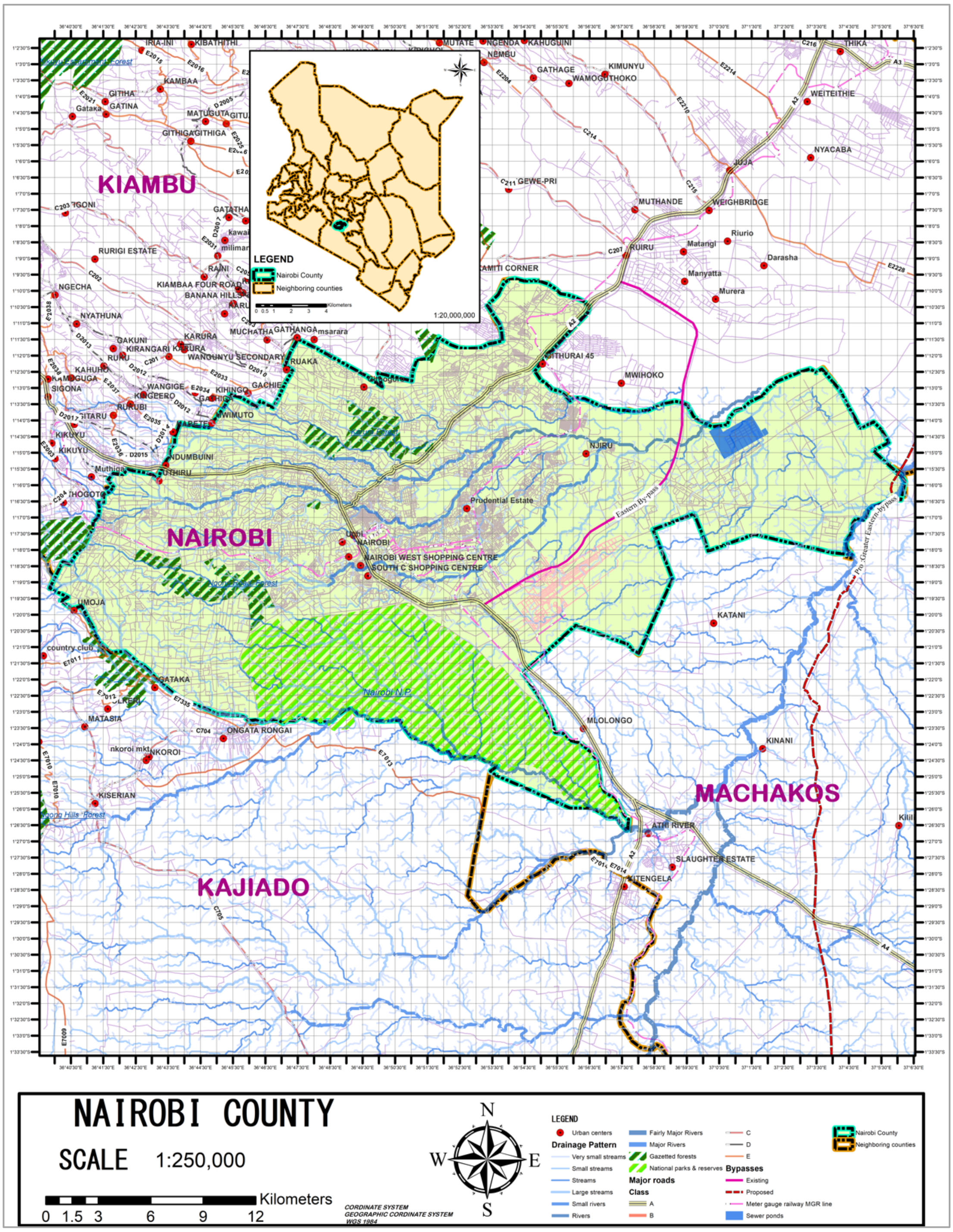


Figure 3.4.1:1 Nairobi County and the neighbouring counties.

Source: Author (2021).

3.4.2 Unit of Analysis

Mugenda and Mugenda (2012) define the unit of analysis as "the element whose data is aggregated and analyzed in the study to make conclusions, decisions or inferences". Having been informed by the research questions, the study unit of analysis were the stakeholders and decision makers, both individuals and organisations, in the construction industry in Nairobi; consultants (project managers, architects, structural engineers, quantity surveyors), developers, contactors, and OSM concrete building elements manufacturers. These were considered decision makers on whether to use or not the OSM concrete building elements in their building construction projects.

3.4.3 Sampling Frame

The sampling frame for this study were consultants (project managers, architects, structural engineers and quantity surveyors), developers, contractors, manufacturers, and researchers.

3.4.4 Sampling Techniques

This study used the non-probability sampling to obtain samples for this study, specifically, the purposive sampling method as this technique permits a researcher to use cases or respondents that have the information needed regarding the objectives of the study (Maina 2012, cited in Odongo 2017). The author targeted an entity or entities that could have been faced with a decision to adopt offsite manufacturing techniques versus onsite techniques, and assess the parameters that led to their decision making. This was based on the author's background check and study of the population so as to objectively select the desired population frame.

3.4.5 Sample Size

Rukwaro (2016) notes that a sample is a portion of a population chosen by some clearly defined set of procedures. Mugenda and Mugenda (2012), cited in Rukwaro (2016) notes that the sample size refers to the number of units, subjects, objects or items in a sample drawn from the population. A minimum of representative sampling is required to be 30no. items (Mugenda and Mugenda 2003, cited in Odongo 2017). The author intended to collect data from a sample size of 110no. units, ended up receiving 79no. responses.

3.5 Data Collection Tools and Techniques

This study used four data collection tools to collect data with the endeavour of achieving the set objectives. They included; i) observation through photographs and sketches; ii) interviews using both structured and unstructured interviews to avoid any relevant information being overlooked; iii) administration of questionnaires; and iv) secondary methods that entailed reviewing all published and unpublished written literature, inclusive of journals and internet sourced information relating to the study research area and that address the research questions.

3.6 Validity and Reliability of Data

3.6.1 Validity

Validity is often defined as "the extent to which an instrument measures what it asserts to measure" (Blumberg et al. 2005, cited in Mohajan 2017). Validity of a research instrument assesses the extent to which the instrument measures what it is designed to measure (Robson 2011, cited in Mohajan 2017). This study adopted triangulation to improve this study's validity through the use of several data collection instruments such as interviews, administration of questionnaires and observations.

3.6.2 Reliability

Reliability refers to a measurement that produces consistent readings with equal values (Blumberg et al. 2005, cited in Mohajan 2017). It measures a research's precision, consistency, repeatability and trustworthiness (Chakrabartty 2013, cited in Mohajan 2017).

Piloting method was used in this study to test on reliability. Structured and semi-structured questionnaires were administered using the pilot study to be able to assess the questionnaire's appropriateness. This helped refine further the questionnaire where the need was. The data collected during the pilot study was compared to the data collected during the actual study to assess on its consistency.

The Cronbach's alpha measure of internal consistency was used to check the reliability statistics. The reliability test of the several items in the questionnaire ranged from 91.0% to 96.3% averaging at 93.1% for the four thematic areas, indicating a high internal consistency and thus reliability.

3.7 Data Analysis Techniques

The data collected from the field, both qualitative and quantitative, was tabulated under different subthemes as set out in the objectives of the study, the operational framework and the questionnaire as captured in Appendix 05. The tabulated data was then further coded using a system of numerical indices for ease of analysis, through computer applications, which included Statistical Package for Social Sciences (SPSS) and Microsoft Excel. Tables, charts and cross-tabulation charts were generated from these computer applications and used for interpretation.

3.8 Data Presentation Techniques

Research findings are presented using a set of presentation criteria so as to achieve good understanding and interpretation of the study such as; i) tables have been used to convey textual and numerical information; ii) photographs have been used to capture onsite use of OSM concrete building elements, offsite fabrication of the OSM concrete building elements and other onsite & offsite factors that constrain the adoption of OSM concrete building elements – the photographs were necessary to support the descriptive text; iii) charts/graphs have been used to present tabular numeric data such as the distribution of survey responses according to respondent's roles, representing it by symbols such as bars in a bar chart; and iv) descriptive words have been used to convey some of the study findings especially where there was need to show the relationship between causal links.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter entails reporting and presentation of the results obtained from the questionnaires administered, interviews conducted and building construction projects visited and observations made. This study's specific areas of interest aligned with the research objectives and research questions, included identifying the types of offsite manufacturing (OSM) of concrete building elements used in building construction projects in Nairobi; identifying the parameters that influence positively and negatively the use of these OSM concrete building elements; establishing parameters that need to be considered in the decision-making to use OSM concrete building elements; and establishing the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi. The study was targeting the built environment stakeholders; project managers, architects, structural engineers, quantity surveyors, developers, contractors, manufacturers, and others within the built environment industry.

4.2 Data Presentation

4.2.1 Respondents' Information

The response was 79 respondents from 109 questionnaires distributed capturing a response rate of 72.48%. The respondents' distribution with regards to their roles in the built environment is as shown in Figure 4.2.1:1.

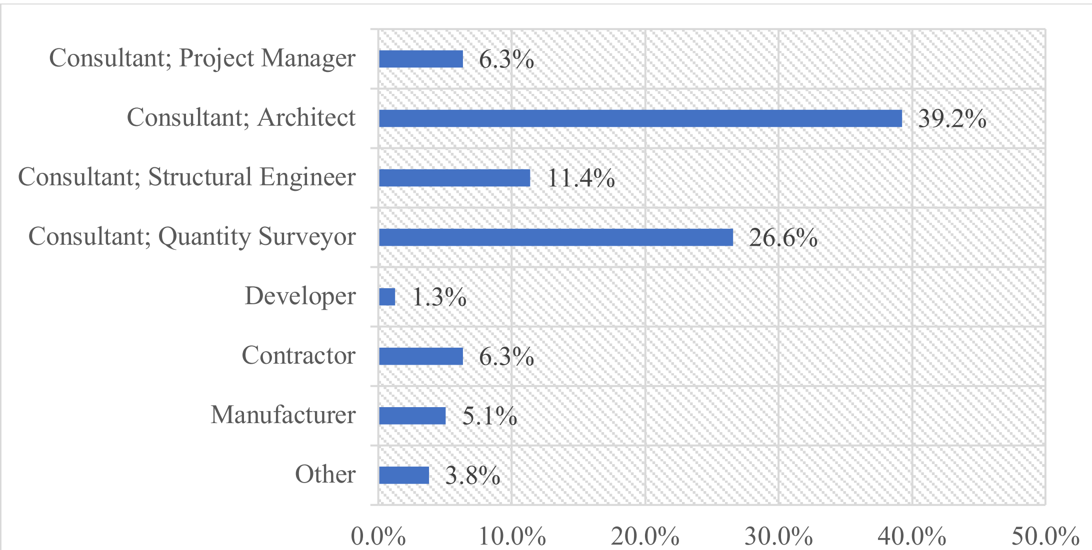


Figure 4.2.1:1 Respondents' roles.
Source: Field survey (2021).

The 79 respondents were as per the following frequencies; 5no. project managers, 31no. architects, 9no. structural engineers, 21no. quantity surveyors, 1no. developer, 5no. contractors, 4no. manufacturers, and 3no. others (1 project manager at a government institution, 1 consultant valuer & lecturer in the built environment, 1 graduate architect). The respondents' categories of organisations were distributed as shown in Figure 4.2.1:2 with 66no. (84%) in private, 12no. (15%) in government, and 1no. (1%) in NGO organisations.

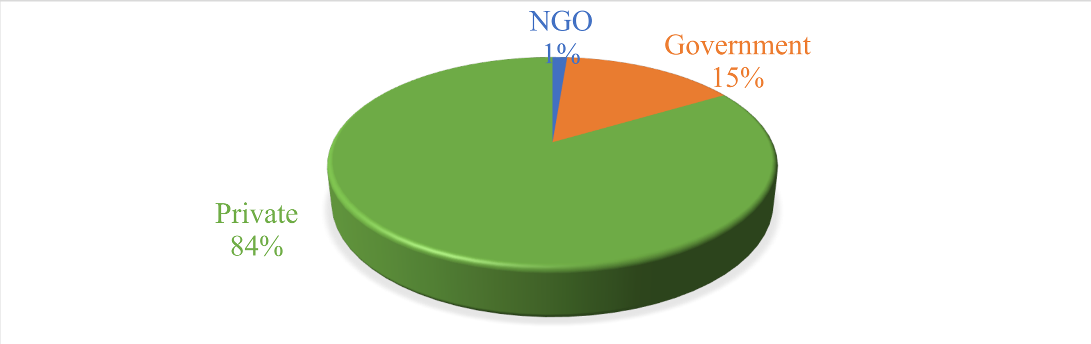


Figure 4.2.1:2 Respondents' categorisation of organisation.
Source: Field survey (2021).

The respondents' professional experience in the built environment was captured as shown in Figure 4.2.1:3 with 11no. 1-3 years, 27no. 4-5 years, 25no. 6-10 years, and 16no. above 10 years. This shows relatively enough respondents' participation in the study from across the different categories of the respondents' professional experience.

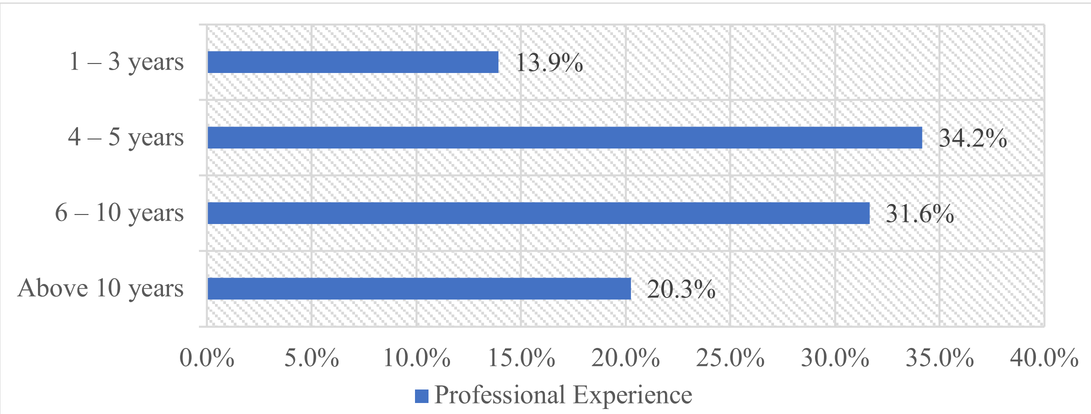
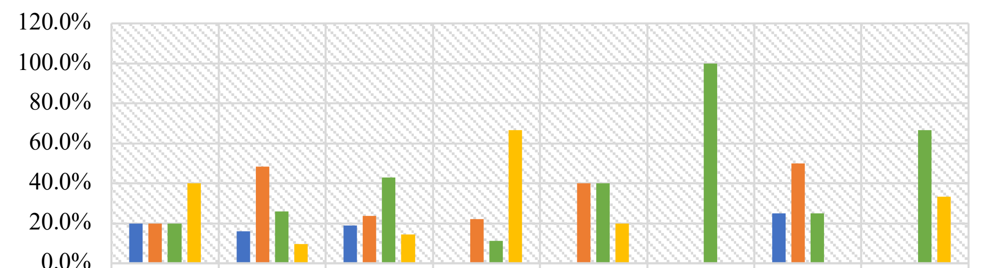


Figure 4.2.1:3 Respondents' professional experience.
Source: Field survey (2021).

In an attempt to elaborate the proportion of the respondents per role in the built environment to the professional experience in the built environment as captured from the field survey, Figure 4.2.1:4 captures the cross-tabulation for that.



	Consultant ; Project Manager	Consultant ; Architect	Consultant ; Quantity Surveyor	Consultant ; Structural Engineer	Contractor	Developer	Manufacturer	Other
1 – 3 years	20.0%	16.1%	19.0%				25.0%	
4 – 5 years	20.0%	48.4%	23.8%	22.2%	40.0%		50.0%	
6 – 10 years	20.0%	25.8%	42.9%	11.1%	40.0%	100.0%	25.0%	66.7%
Above 10 years	40.0%	9.7%	14.3%	66.7%	20.0%			33.3%

Figure 4.2.1:4 Cross-tabulation of role vs professional experience.
Source: Field survey (2021).

Majority (40%) of the respondents who are project managers have more than 10 years of professional experience in the built environment; for architects, majority (48.4%) have 4-5 years; for quantity surveyors, majority (42.9%) have 6-10 years; for structural engineers, majority (66.7%) have more than 10 years; for contractors, majority (40%) have 6-10 years and another 40% with 4-5 years; for developers, all (100%) have 6-10 years; for manufacturers, majority (50%) have 4-5 years; and for the others, majority (66.7%) have more than 10 years of professional experience in the built environment industry.

4.2.2 Usage of OSM Concrete Building Elements

The first objective of this study was to identify the types of offsite manufacturing of concrete building elements used in building construction projects in Nairobi. The study revealed that it's only the non-volumetric type that's used by the respondents, while the volumetric and modular are not. 48no. respondents (61%) noted to have used the OSM concrete building elements in their building construction projects in Nairobi while 31no. respondents (39%) to have not, as shown in Figure 4.2.2:1.

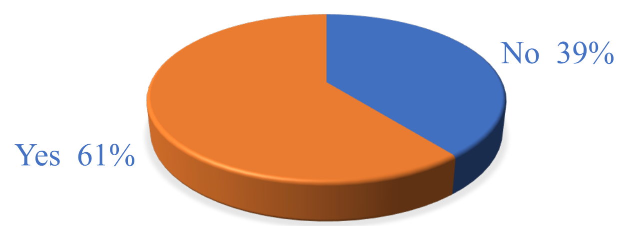


Figure 4.2.2:1 Usage of OSM concrete building elements.
Source: Field survey (2021).

All 48no. respondents who had used the OSM concrete building elements, had used the non-volumetric type. Of the 31no. respondents who had not used the OSM concrete building elements; 19no. considered using the OSM concrete building elements, but did not use while 11no. did not consider using the OSM concrete building elements.

Table 4.2.2:1 shows the respondents' roles to whether they have used OSM concrete building elements. Majority (80%) of the respondents who are project managers have used OSM concrete building elements; for architects, majority (51.6%) have used; for structural engineers, majority (55.6%) have not used; for quantity surveyors, majority (66.7%) have used; for contractors, majority (80%) have used; for developers, all (100%) have not used; for manufacturers, all (100%) have used; and for the others, majority (66.7%) have used.

Table 4.2.2:1 Respondents' roles vs usage.

Respondents' roles	Yes	% of total	No	% of total
Manufacturer	100.0%	5.1%	0.0%	0.0%
Consultant; Project Manager	80.0%	5.1%	20.0%	1.3%
Contractor	80.0%	5.1%	20.0%	1.3%
Consultant; Quantity Surveyor	66.7%	17.7%	33.3%	8.9%
Other	66.7%	2.5%	33.3%	1.3%
Consultant; Architect	51.6%	20.3%	48.4%	19.0%
Consultant; Structural Engineer	44.4%	5.1%	55.6%	6.3%
Developer	0.0%	0.0%	100.0%	1.3%

Source: Field survey (2021).

Figure 4.2.2:2 shows the cross-tabulation of the respondents' categorisation of their organisation to whether they have used the OSM concrete building elements. This shows majority, 65.2% of the 66no. respondents in private organisations, have used the OSM concrete building elements.

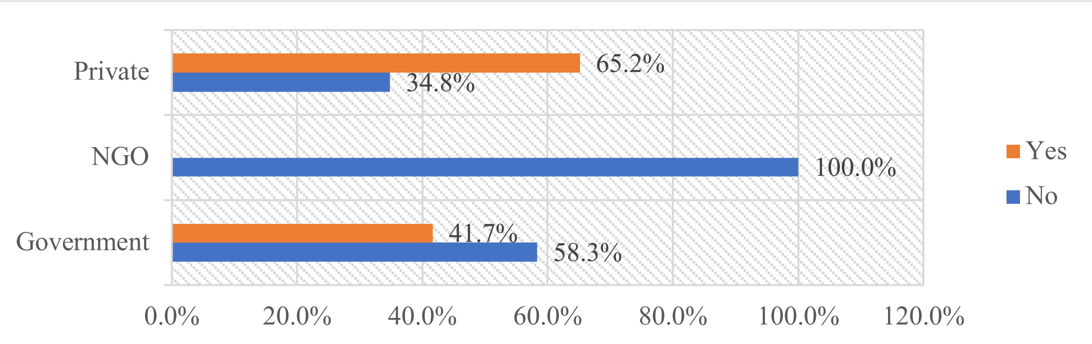


Figure 4.2.2:2 Cross-tabulation of categorisation of organisation vs usage.
Source: Field survey (2021).

With regards to the types of the OSM concrete building elements/products the respondents had used in their building construction projects in Nairobi, Figure 4.2.2:3 shows that. The data from the survey shows that precast slabs are the most commonly used OSM concrete building elements by the respondents, accounting for 63.9% of the 48no. respondents who have used the OSM concrete building elements. The least used OSM concrete building elements are the precast foundation piles (2.8%). In most cases, the respondents have used more than one OSM concrete building elements.

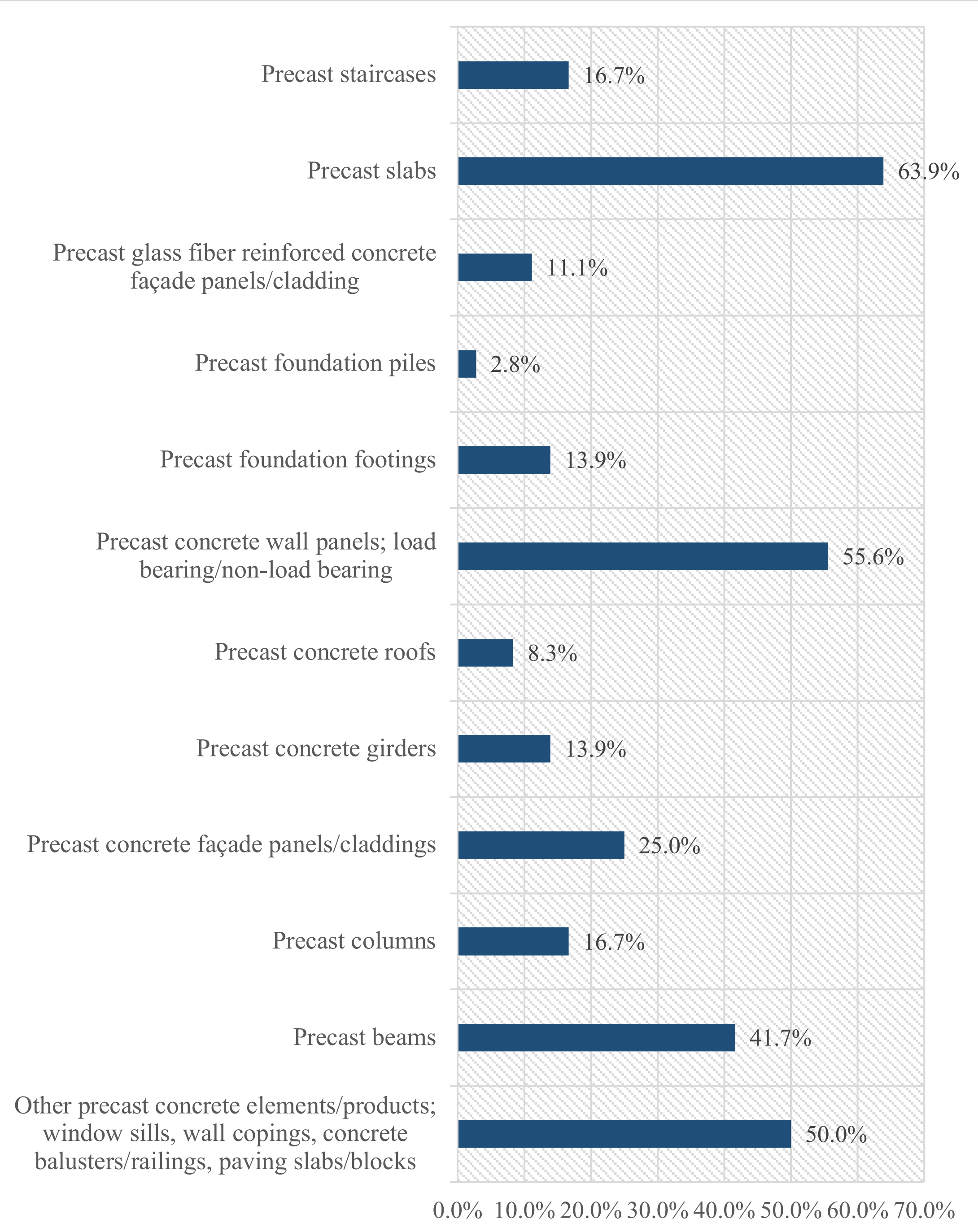


Figure 4.2.2:3 The OSM concrete building elements/products used.
Source: Field survey (2021).

Figures 4.2.2:4-6 shows some of the OSM concrete building elements as captured by the author during visits to sites and offsite manufacturing sites.

Figure 4.2.2:4 Precast beams and block at an OSM site. Source: Author (2021).

These precast beams are used alongside concrete blocks (solid or hollow) for floor slabs spanning up to 6.5m & 10m for 150mm & 225mm deep beams respectively.

Figure 4.2.2:5 Precast wall panels used on an active site. Source: Author (2021).

Figure 4.2.2:6 A building with precast wall panels used for all walling works. Source: Author (2021).

4.2.3 Positive Influence

How the parameters influenced positively the decision to use OSM concrete building elements

Respondents were asked how the variables/parameters (cost; schedule/time; labour and productivity; scope; quality, predictability and reliability; risk; research and development; sustainability – environmental, social, cultural and economic dimensions; and other parameters in their opinion) influenced their decision positively to use offsite manufacturing of concrete building elements in their building construction projects in Nairobi. The consideration level scoring for this was done using a 5-point likert scale, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high consideration, 5 = very high consideration. Below is the report on findings as captured from the survey. The figures and tables under each variable in this section shows how the respondents responded on how the different parameters under each variable influenced their decision positively to use OSM concrete building elements.

i) Cost

The parameters assessed were: initial capital costs (fabrication facility costs); upfront design fees costs; material, labour, and time costs; transportation costs & craneage; and lifecycle costs. Figure 4.2.3:1 and Table 4.2.3:1 show the respondents' levels of consideration. Material, labour, and time costs had the highest mean of 3.766 (high consideration) with a low standard deviation (SD) of 1.2196 while upfront design fees costs had the lowest mean of 2.532 with SD of 1.4574.

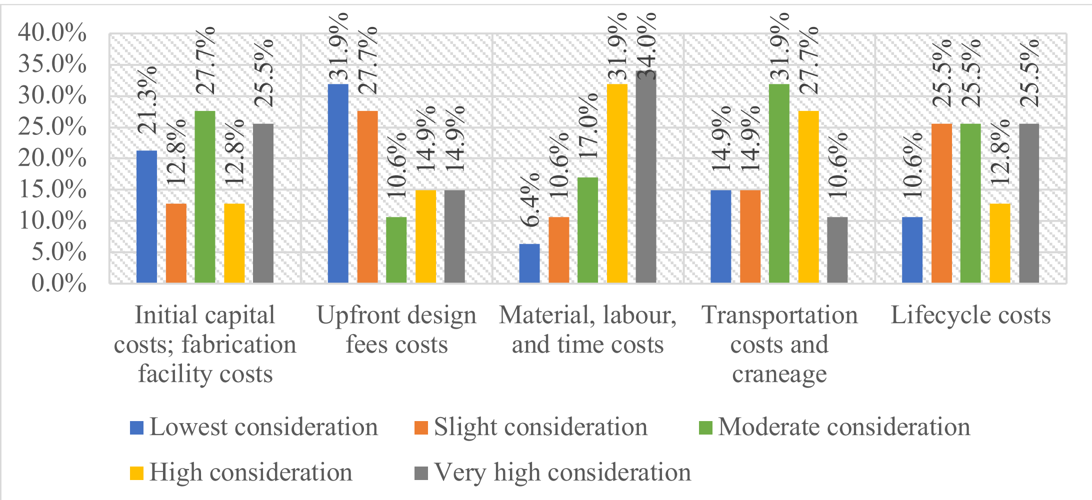


Figure 4.2.3:1 Cost parameters.
Source: Field survey (2021).

Table 4.2.3:1 Descriptive statistics for cost parameters.

Cost parameters	N	Mean	Std. deviation
Initial capital costs; fabrication facility costs	47	3.085	1.4719
Upfront design fees costs	47	2.532	1.4574
Lifecycle costs	47	3.170	1.3565
Material, labour, and time costs	47	3.766	1.2196
Transportation costs and craneage	47	3.043	1.2151

Source: Field survey (2021).

ii) Schedule/time

The parameters assessed were: delivery duration; and installation duration (sequencing & overlap). Figure 4.2.3:4 and Table 4.2.3:2 show the respondents' levels of consideration. Installation duration (sequencing & overlap) had the highest mean of 4.333 (very high consideration) with the lowest SD of 1.0176 while delivery duration had the lower mean of 4.104 with SD of 1.2922.

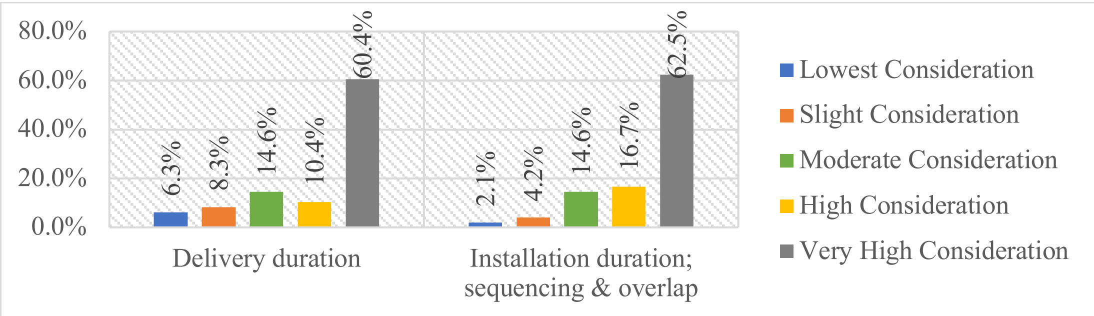


Figure 4.2.3:2 Schedule/time parameters.
Source: Field survey (2021).

Table 4.2.3:2 Descriptive statistics for schedule/time parameters.

Schedule/time parameters	N	Mean	Std. deviation
Delivery duration	48	4.104	1.2922
Installation duration; sequencing & overlap	48	4.333	1.0176

Source: Field survey (2021).

iii) Labour and productivity

The parameters assessed were: skilled; prefabrication technology technical know-how/knowledge; training; and mindset/perception of productivity efficiency. Figure 4.2.3:5 and Table 4.2.3:3 show the respondents' levels of consideration. Prefabrication technology technical know-how/knowledge had the highest mean of 3.854 (high consideration) with a low SD of 1.2202 while training had the lowest mean of 3.479 with SD of 1.2881.

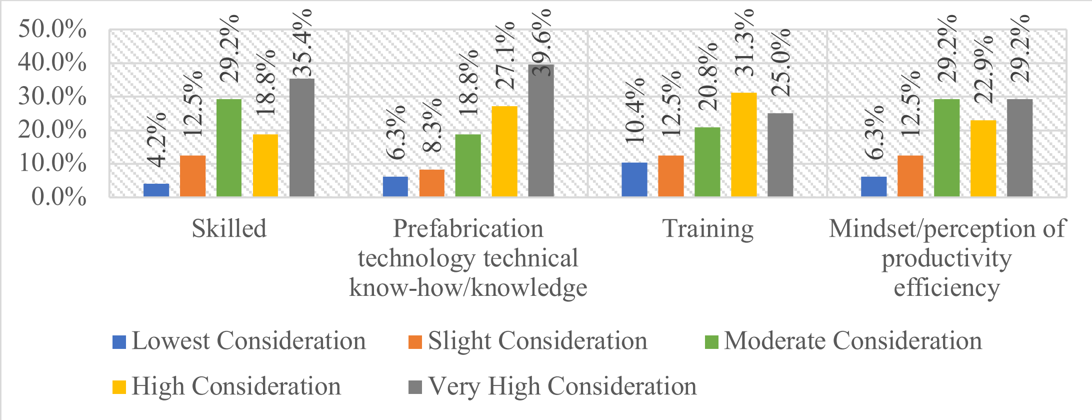


Figure 4.2.3:3 Labour and productivity parameters.
Source: Field survey (2021).

Table 4.2.3:3 Descriptive statistics for labour and productivity.

Labour and productivity parameters	N	Mean	Std. deviation
Training	48	3.479	1.2881
Prefabrication technology technical know-how/knowledge	48	3.854	1.2202
Mindset/perception of productivity efficiency	48	3.563	1.2188
Skilled	48	3.688	1.2056

Source: Field survey (2021).

iv) Scope

The parameters assessed were: complexity/extent of project; integration of design team & construction team; and supply chain management. Figure 4.2.3:6 and Table 4.2.3:4 show the respondents' levels of consideration. Complexity/extent of project had the highest mean of 3.521 (high consideration) with a low SD of 1.4438 while supply chain management had the lowest mean of 3.319 with SD of 1.3369.

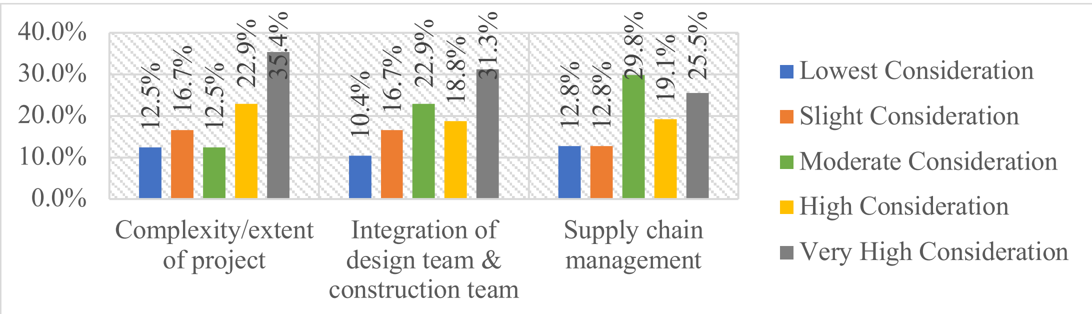


Figure 4.2.3:4 Scope parameters.
Source: Field survey (2021).

Table 4.2.3:4 Descriptive statistics for scope parameters.

Scope parameters	N	Mean	Std. deviation
Complexity/extent of project	48	3.521	1.4438

Integration of design team & construction team	48	3.438	1.3669
Supply chain management	47	3.319	1.3369

Source: Field survey (2021).

v) Quality, predictability and reliability

The parameters assessed were: workmanship; achieving specifications issued, by production & products quality and design quality; and durability. Figure 4.2.3:7 and Table 4.2.3:5 show the respondents' levels of consideration. Workmanship had the highest mean of 4.292 (very high consideration) with a low SD of 0.8742 while durability had the lowest mean of 3.723 with SD of 1.2972.

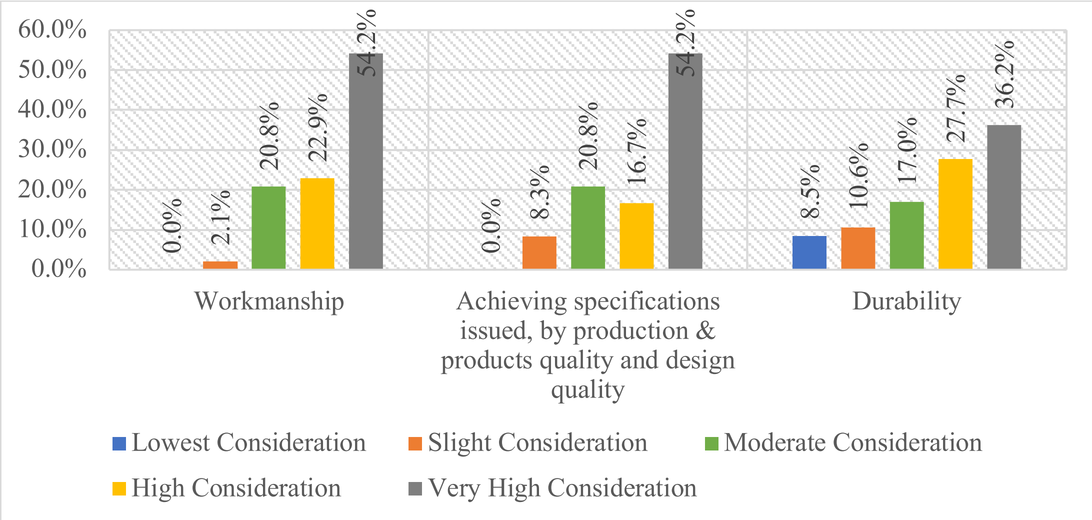


Figure 4.2.3:5 Quality, predictability and reliability parameters.
Source: Field survey (2021).

Table 4.2.3:5 Descriptive statistics for quality, predictability & reliability.

Quality, predictability and reliability parameters	N	Mean	Std. deviation
Durability	47	3.723	1.2972
Achieving specifications issued, by production & products quality and design quality	48	4.167	1.0383
Workmanship	48	4.292	0.8742

Source: Field survey (2021).

vi) Risk

The parameters assessed were: quality (unverified fabricators); financial vulnerability to clients, designers and contractors; safety and health (exposure to hazards); and extended producer responsibility (EPR). Figure 4.2.3:8 and Table 4.2.3:6 show the respondents' levels of consideration. Safety and health (exposure to hazards) had the highest mean of 3.583 (high consideration) with a low SD of 1.2348 while EPR had the lowest mean of 3.191 with SD of 1.3774.

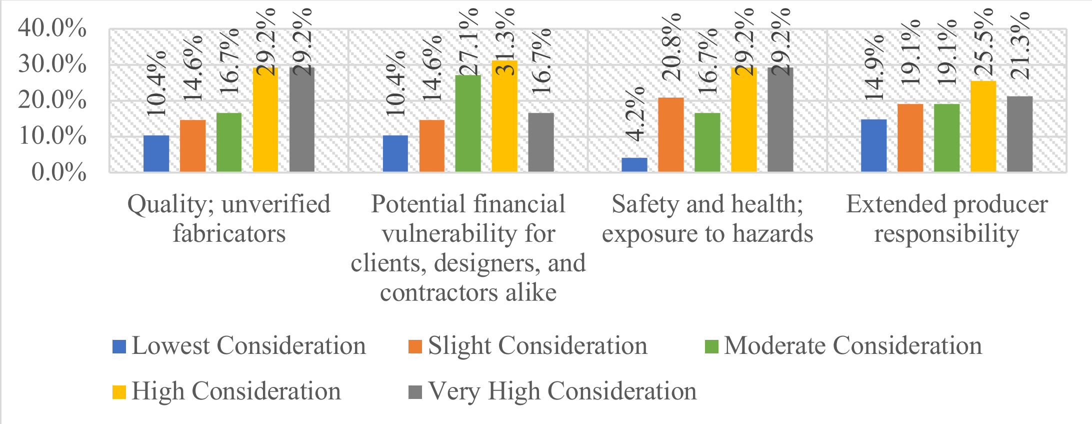


Figure 4.2.3:6 Risk parameters.
Source: Field survey (2021).

Table 4.2.3:6 Descriptive statistics for risk parameters.

Risk parameters	N	Mean	Std. deviation
Extended producer responsibility	47	3.191	1.3774
Quality; unverified fabricators	48	3.521	1.3367
Safety and health; exposure to hazards	48	3.583	1.2348
Financial vulnerability to clients, designers and contractors	48	3.292	1.2197

Source: Field survey (2021).

vii) Research and development

The parameters assessed were: contractor design-assist delivery; and cost cutting strategies. Figure 4.2.3:9 and Table 4.2.3:7 show the respondents' levels of consideration. Cost cutting strategies had the highest mean of 4.063 (very high consideration) with a low SD of 1.0994 while contractor design-assist delivery had the lower mean of 3.563 with SD of 1.2012.

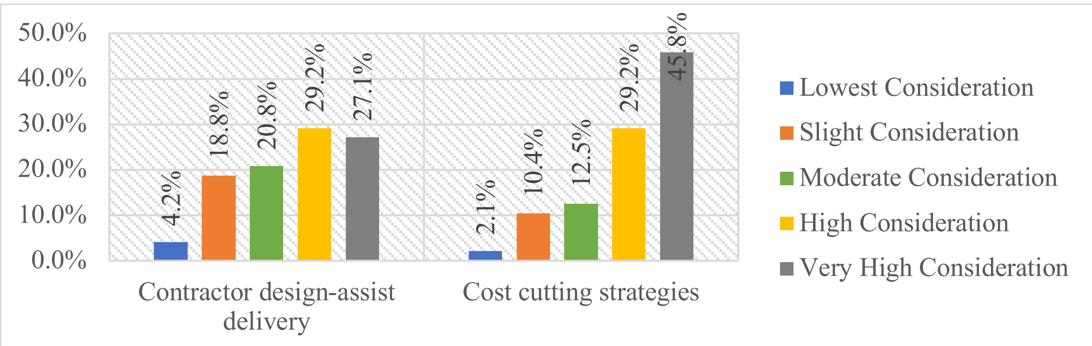


Figure 4.2.3:7 Research and development parameters.
Source: Field survey (2021).

Table 4.2.3:7 Descriptive statistics for research and development parameters.

Research and development parameters	N	Mean	Std. deviation
Contractor design-assist delivery	48	3.563	1.2012
Cost cutting strategies	48	4.063	1.0994

Source: Field survey (2021).

viii) Sustainability; environmental dimension

The parameters assessed were: use of sustainable local materials; preventing hazardous and polluting materials; and site disturbance. Figure 4.2.3:10 and Table 4.2.3:8 show the respondents' levels of consideration. Site disturbance had the highest mean of 3.813 (high consideration) with a low SD of 1.2489 while preventing hazardous and polluting materials had the lowest mean of 3.340 with SD of 1.4337.

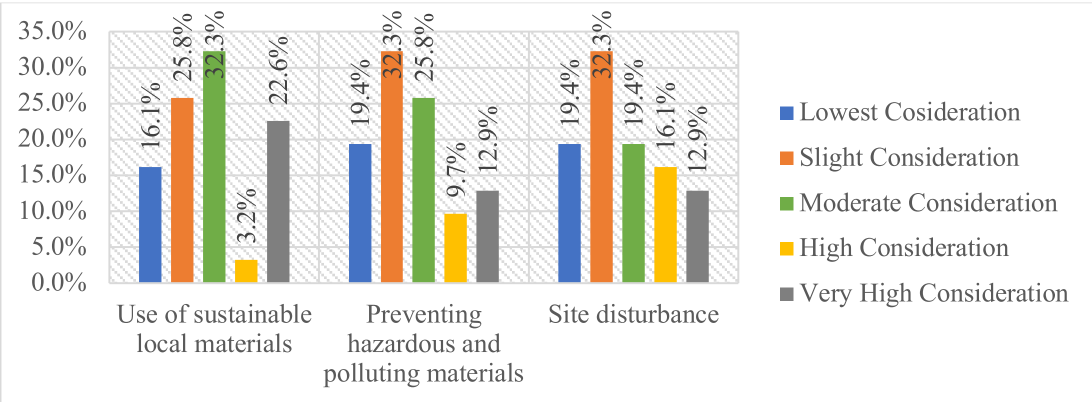


Figure 4.2.3:8 Sustainability; environmental dimension parameters.
Source: Field survey (2021).

Table 4.2.3:8 Descriptive statistics for sustainability; environmental dimension.

Sustainability; environmental dimension parameters	N	Mean	Std. deviation
Preventing hazardous and polluting materials	47	3.340	1.4337
Use of sustainable local materials	48	3.458	1.4136
Site disturbance	48	3.813	1.2489

Source: Field survey (2021).

ix) Sustainability; social dimension

The parameters assessed were: awareness & public participation; health, safety & wellbeing in the built forms; and jobs created with prefabrication. Figure 4.2.3:11 and Table 4.2.3:9 show the respondents' levels of consideration. Health, safety & wellbeing in the built forms had the highest mean of 3.553 (high consideration) with a low SD of 1.4266 while awareness & public participation had the lowest mean of 2.723 with SD of 1.3941.

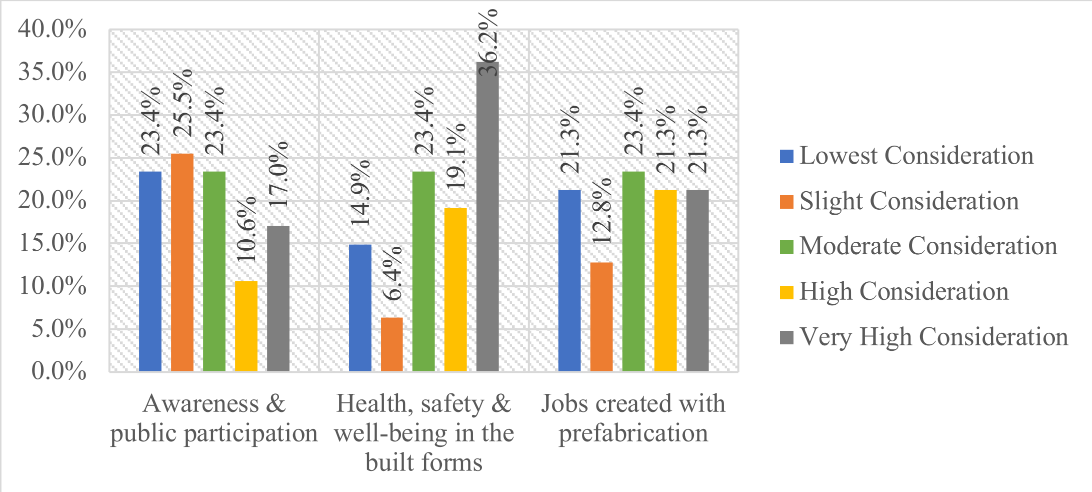


Figure 4.2.3:9 Sustainability; social dimension parameters.
Source: Field survey (2021).

Table 4.2.3:9 Descriptive statistics for sustainability; social dimension parameters.

Sustainability; social dimension parameters	**N**	**Mean**	**Std. deviation**
Jobs created with prefabrication	47	3.085	1.4421
Health, safety & wellbeing in the built forms	47	3.553	1.4266
Awareness & public participation	47	2.723	1.3941

Source: Field survey (2021).

x) Sustainability; cultural dimension

The parameters assessed were: aesthetics (culturally responsive built forms); and promotion of local materials & building techniques. Figure 4.2.3:12 and Table 4.2.3:10 show the respondents' levels of consideration. Aesthetics (culturally responsive built forms) had the highest mean of 3.583 (high consideration) with a low SD of 1.3342 while promotion of local materials & building techniques had the lower mean of 3.333 with SD of 1.3422.

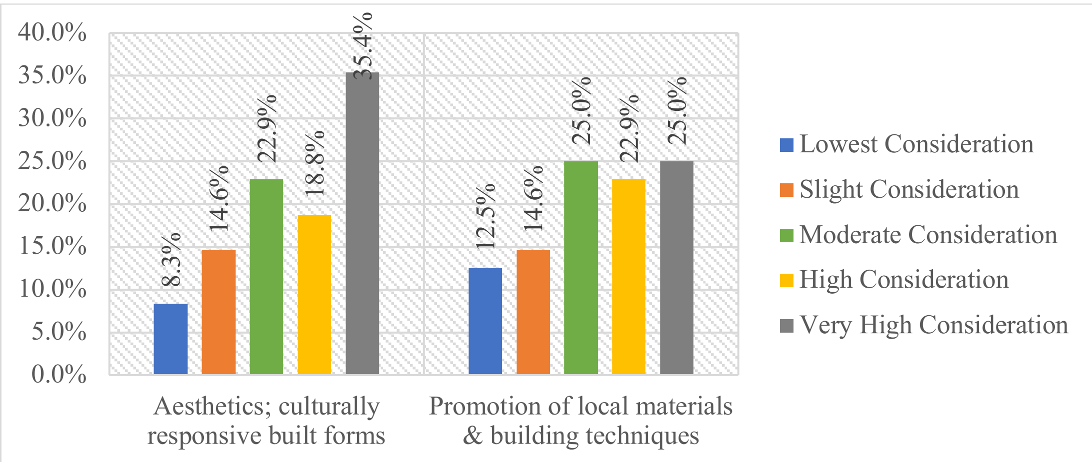


Figure 4.2.3:10 Sustainability; cultural dimension parameters.
Source: Field survey (2021).

Table 4.2.3:10 Descriptive statistics for sustainability; cultural dimension.

Sustainability; cultural dimension parameters	N	Mean	Std. deviation
Promotion of local materials & building techniques	48	3.333	1.3422
Aesthetics; culturally responsive built forms	48	3.583	1.3342

Source: Field survey (2021).

xi) Sustainability; economic dimension

The parameters assessed were: affordability on construction costs; and post-occupancy operations. Figure 4.2.3:13 and Table 4.2.3:11 show the respondents' levels of consideration. Affordability on construction costs had the highest mean of 4.000 (high consideration) with a low SD of 1.2204 while post-occupancy operations had the lower mean of 3.468 with SD of 1.2828.

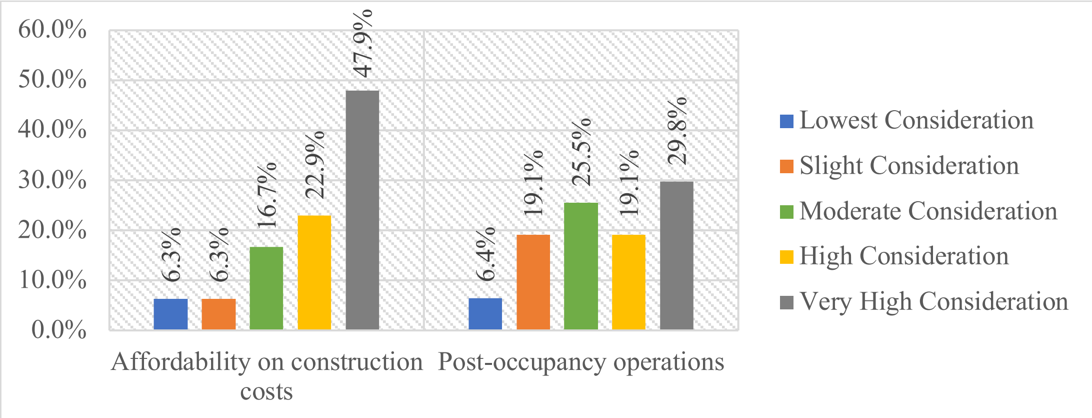


Figure 4.2.3:11 Sustainability; economic dimension parameters.
Source: Field survey (2021).

Table 4.2.3:11 Descriptive statistics for sustainability; economic dimension.

Sustainability; economic dimension parameters	N	Mean	Std. deviation
Post-occupancy operations	47	3.468	1.2828
Affordability on construction costs	48	4.000	1.2204

Source: Field survey (2021).

xii) Other parameters

The parameters assessed were: awareness of the OSM techniques; influence from government projects executed using the OSM techniques; research and development advancements; retrained and reskilled labour force; favorable government policy, incentives and promotion; favorable building code and statutory approvals; current and less capital intensive OSM techniques disseminated. Figure 4.2.3:14 and Table 4.2.3:12 show the respondents' levels of consideration. Awareness of the OSM techniques had the highest mean of 3.521 (high consideration) with a low SD of 1.2026 while influence from government projects executed using the OSM techniques had the lowest mean of 2.271 with SD of 1.3486.

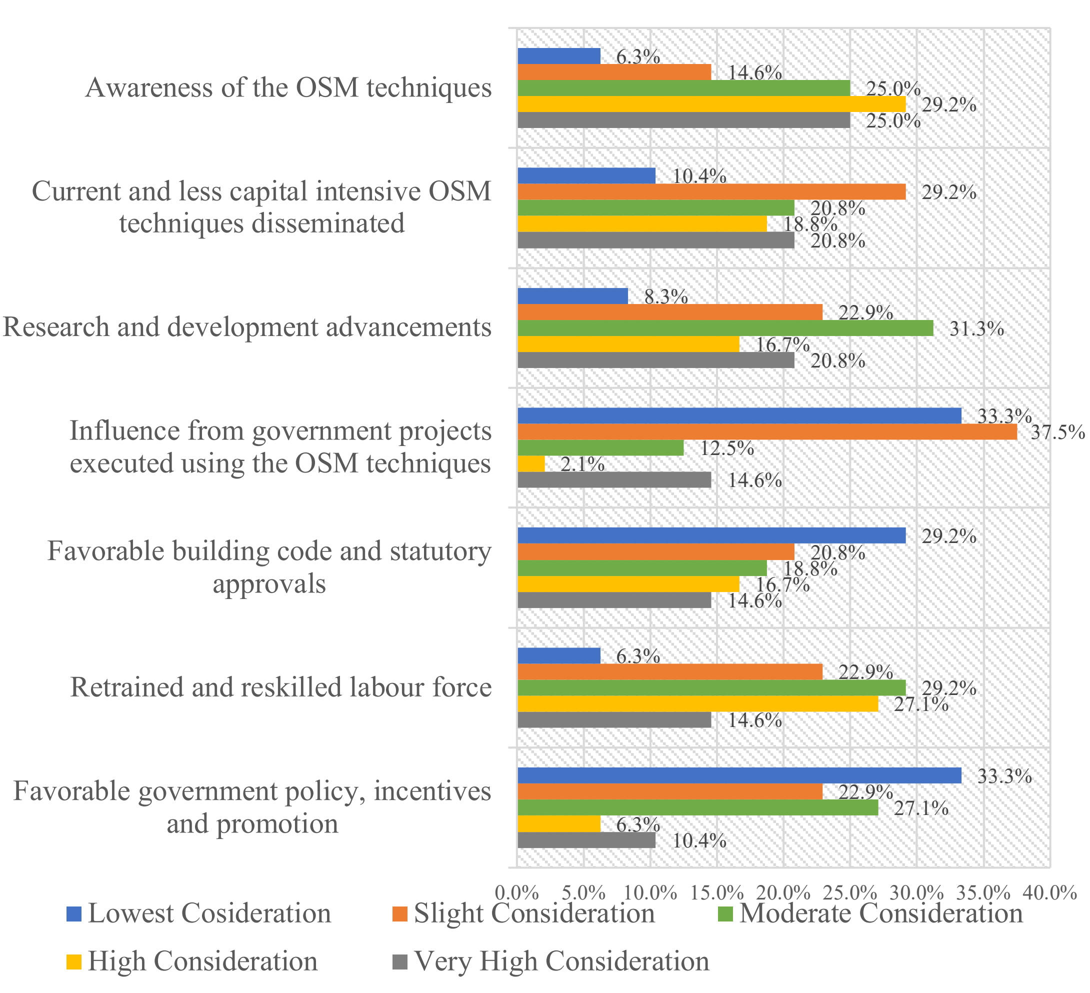


Figure 4.2.3:12 Other parameters that influenced positively.
Source: Field survey (2021).

Table 4.2.3:12 Descriptive statistics for other parameters.

Other parameters	**N**	**Mean**	**Std. deviation**
Favorable building code and statutory approvals	48	2.667	1.4341
Influence from government projects executed using the OSM techniques	48	2.271	1.3486
Current and less capital intensive OSM techniques disseminated	48	3.104	1.3247
Favorable government policy, incentives and promotion	48	2.375	1.2985
Research and development advancements	48	3.188	1.2489
Awareness of the OSM techniques	48	3.521	1.2026
Retrained and reskilled labour force	48	3.208	1.1478

Source: Field survey (2021).

4.2.4 Negative Influence

How the parameters influenced negatively the decision to not use OSM concrete building elements

Respondents were asked how the variables/parameters (cost; schedule/time; labour and productivity; scope; quality, predictability and reliability; risk; research and development; sustainability – environmental, social, cultural and economic dimensions; and other parameters in their opinion) informed their decision negatively to not use offsite manufacturing of concrete building elements in their building construction projects in Nairobi. The consideration level scoring for this was done using a 5-point likert scale, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high consideration, 5 = very high consideration. Below is the report on findings as captured from the survey. The figures and tables under each variable in this section shows how the respondents responded on how the different parameters under each variable influenced their decision negatively to not use OSM concrete building elements.

i) Cost

The parameters assessed were: initial capital costs (fabrication facility costs); upfront design fees costs; material, labour, and time costs; transportation costs & craneage; and lifecycle costs. Figure 4.2.4:1 and Table 4.2.4:1 show the respondents' levels of consideration. Transportation costs & craneage had the highest mean of 4.065 (very high consideration) with a low standard deviation (SD) of 1.2093 while lifecycle costs had the lowest mean of 2.258 with SD of 1.2374.

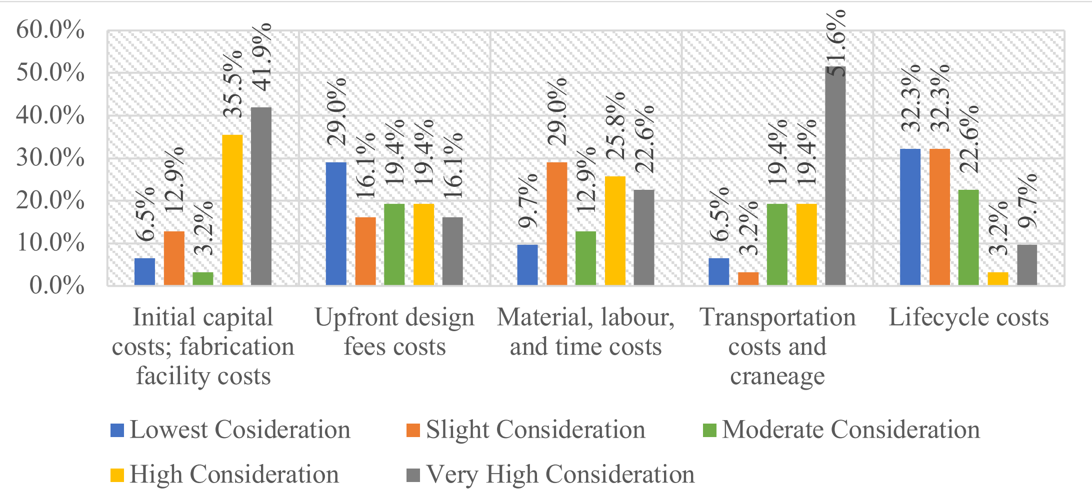


Figure 4.2.4:1 Cost parameters.
Source: Field survey (2021).

Table 4.2.4:1 Descriptive statistics for cost parameters.

Cost parameters	N	Mean	Std. deviation
Upfront design fees costs	31	2.774	1.4767
Transportation costs and craneage	31	4.065	1.2093
Material, labour, and time costs	31	3.226	1.3592
Lifecycle costs	31	2.258	1.2374
Initial capital costs; fabrication facility costs	31	3.935	1.2632

Source: Field survey (2021).

ii) Schedule/time

The parameters assessed were: delivery duration; and installation duration (sequencing & overlap). Figure 4.2.4:2 and Table 4.2.4:2 show the respondents' levels of consideration. Delivery duration had the highest mean of 2.935 (moderate consideration) with a SD of 1.6520 while installation duration (sequencing & overlap) had the lower mean of 2.677 with SD of 1.3512.

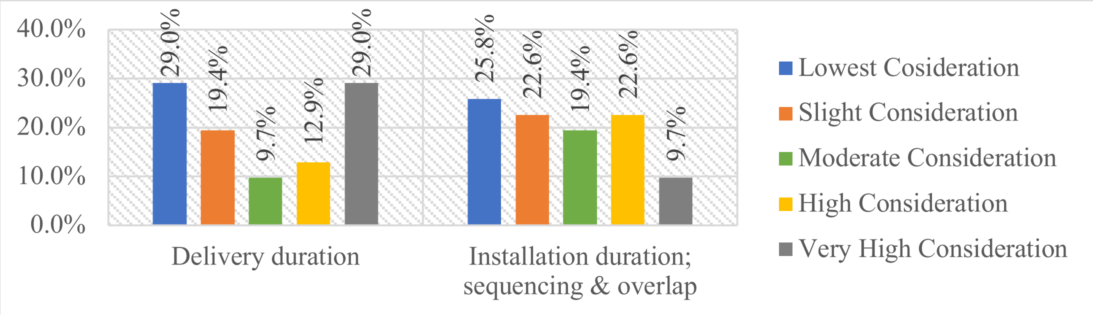


Figure 4.2.4:2 Schedule/time parameters.
Source: Field survey (2021).

Table 4.2.4:2 Descriptive statistics for schedule/time parameters.

Schedule/time parameters	N	Mean	Std. deviation
Delivery duration	31	2.935	1.6520
Installation duration; sequencing & overlap	31	2.677	1.3512

Source: Field survey (2021).

iii) Labour and productivity

The parameters assessed were: unskilled; prefabrication technology technical know-how/knowledge; training; and mindset/perception of productivity efficiency. Figure 4.2.4:3 and Table 4.2.4:3 show the respondents' levels of consideration. Prefabrication technology technical know-how/knowledge had the highest mean of 3.774 (high consideration) with a low SD of 1.3344 while mindset/perception of productivity efficiency had the lowest mean of 3.161 with SD of 1.3928.

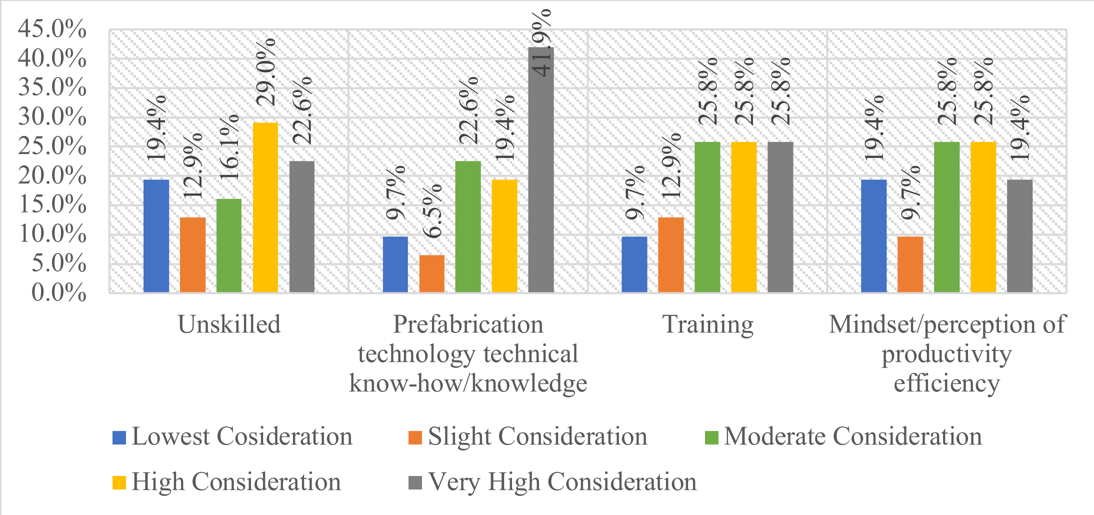


Figure 4.2.4:3 Labour and productivity parameters.
Source: Field survey (2021).

Table 4.2.4:3 Descriptive statistics for labour and productivity parameters.

Labour and productivity parameters	N	Mean	Std. deviation
Unskilled	31	3.226	1.4540
Mindset/perception of productivity efficiency	31	3.161	1.3928
Prefabrication technology technical know-how/knowledge	31	3.774	1.3344
Training	31	3.452	1.2868

Source: Field survey (2021).

iv) Scope

The parameters assessed were: complexity/extent of project; integration of design team & construction team; and supply chain management. Figure 4.2.4:4 and Table 4.2.4:4 show the respondents' levels of consideration. Complexity/extent of project had the highest mean of 3.613 (high consideration) with a low SD of 1.3084 while supply chain management had the lowest mean of 2.839 with SD of 1.3440.

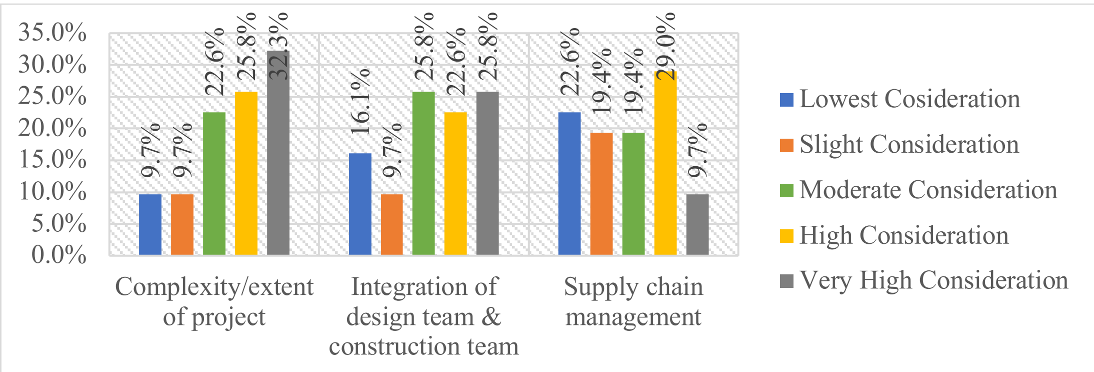


Figure 4.2.4:4 Scope parameters that influenced negatively.
Source: Field survey (2021).

Table 4.2.4:4 Descriptive statistics for scope parameters.

Scope parameters	**N**	**Mean**	**Std. deviation**
Integration of design team & construction team	31	3.323	1.3997
Supply chain management	31	2.839	1.3440
Complexity/extent of project	31	3.613	1.3084

Source: Field survey (2021).

v) Quality, predictability and reliability

The parameters assessed were: workmanship; achieving specifications issued, by production & products quality and design quality; and durability. Figure 4.2.4:5 and Table 4.2.4:5 show the respondents' levels of consideration. Workmanship had the highest mean of 3.161 (high consideration) with a low SD of 1.3686 while durability had the lowest mean of 2.419 with SD of 1.3108.

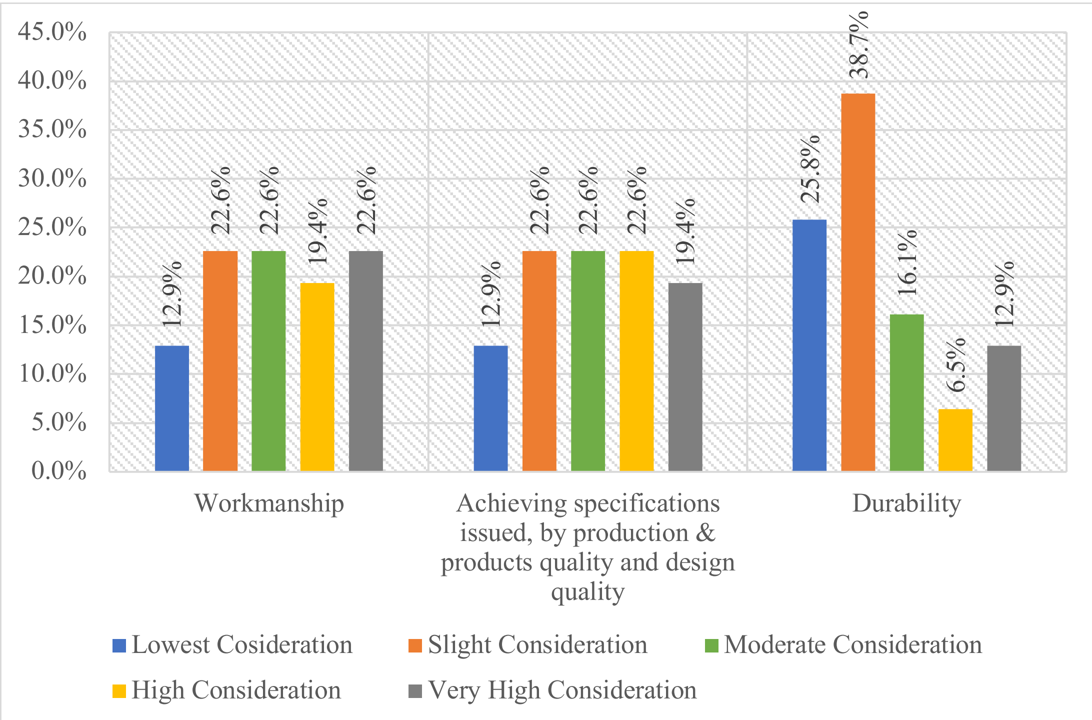


Figure 4.2.4:5 Quality, predictability and reliability parameters.
Source: Field survey (2021).

Table 4.2.4:5 Descriptive statistics for quality, predictability & reliability.

Quality, predictability and reliability parameters	**N**	**Mean**	**Std. deviation**
Workmanship	31	3.161	1.3686
Achieving specifications issued, by production & products quality and design quality	31	3.129	1.3352
Durability	31	2.419	1.3108

Source: Field survey (2021).

vi) Risk

The parameters assessed were: quality (unverified fabricators); financial vulnerability to clients, designers and contractors; safety and health (exposure to hazards); and extended producer responsibility (EPR). Figure 4.2.4:6 and Table 4.2.4:6 show the respondents' levels of consideration. Financial vulnerability to clients, designers and contractors had the highest mean of 3.613 (high consideration) with a low SD of 1.4066 while safety and health (exposure to hazards) had the lowest mean of 2.516 with the lowest SD of 1.2075.

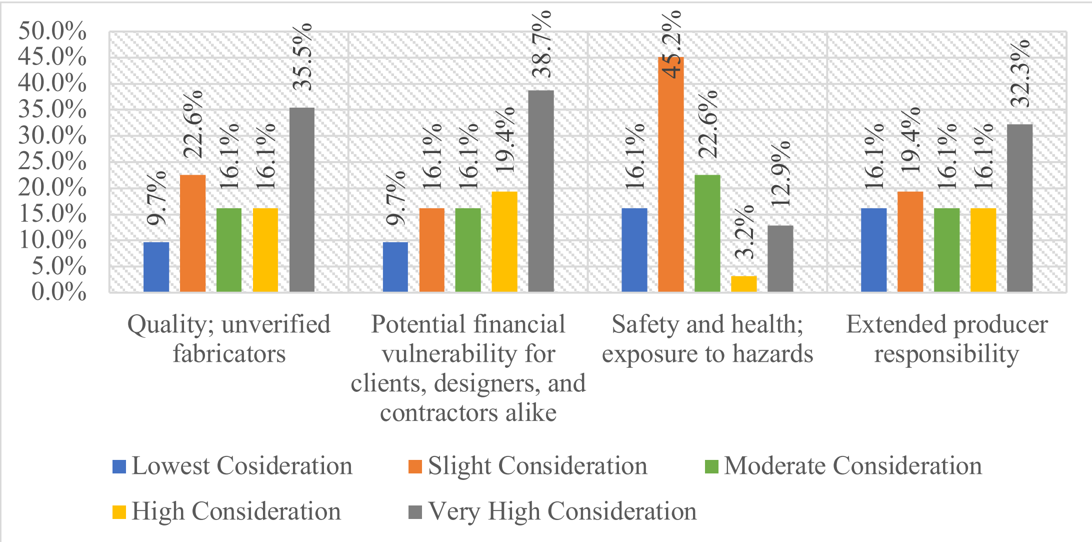


Figure 4.2.4:6 Risk parameters.
Source: Field survey (2021).

Table 4.2.4:6 Descriptive statistics for risk parameters.

Risk parameters	N	Mean	Std. deviation
Extended producer responsibility	31	3.290	1.5098
Quality; unverified fabricators	31	3.452	1.4338
Financial vulnerability to clients, designers and contractors	31	3.613	1.4066
Safety and health; exposure to hazards	31	2.516	1.2075

Source: Field survey (2021).

vii) Research and development

The parameters assessed were: contractor design-assist delivery; and cost cutting strategies. Figure 4.2.4:7 and Table 4.2.4:7 show the respondents' levels of consideration. Cost cutting strategies had the highest mean of 3.194 (high consideration) with a low SD of 1.4005 while contractor design-assist delivery had the lower mean of 3.032 with SD of 1.2776.

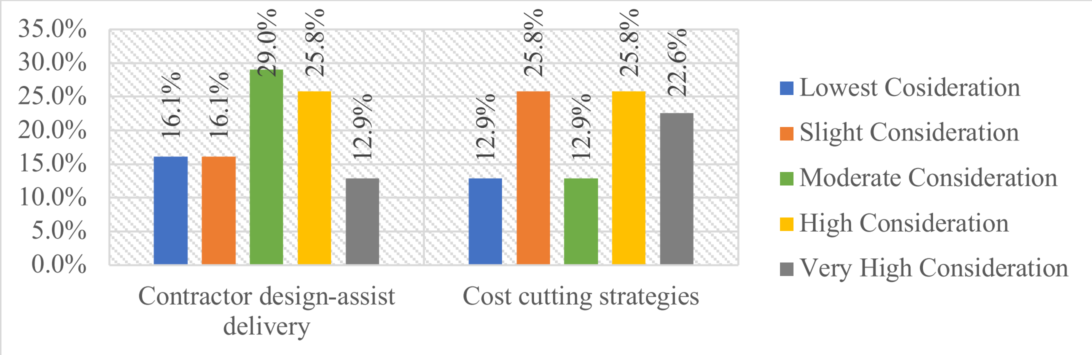


Figure 4.2.4:7 Research and development parameters.
Source: Field survey (2021).

Table 4.2.4:7 Descriptive statistics for research and development parameters.

Research and development parameters	N	Mean	Std. deviation
Cost cutting strategies	31	3.194	1.4005
Contractor design-assist delivery	31	3.032	1.2776

Source: Field survey (2021).

viii) Sustainability; environmental dimension

The parameters assessed were: use of sustainable local materials; preventing hazardous and polluting materials; and site disturbance. Figure 4.2.4:8 and Table 4.2.4:8 show the respondents' levels of consideration. Use of sustainable local materials had the highest mean of 2.903 (moderate consideration) with a low SD of 1.3749 while preventing hazardous and polluting materials had the lowest mean of 2.645 with the lowest SD of 1.2793.

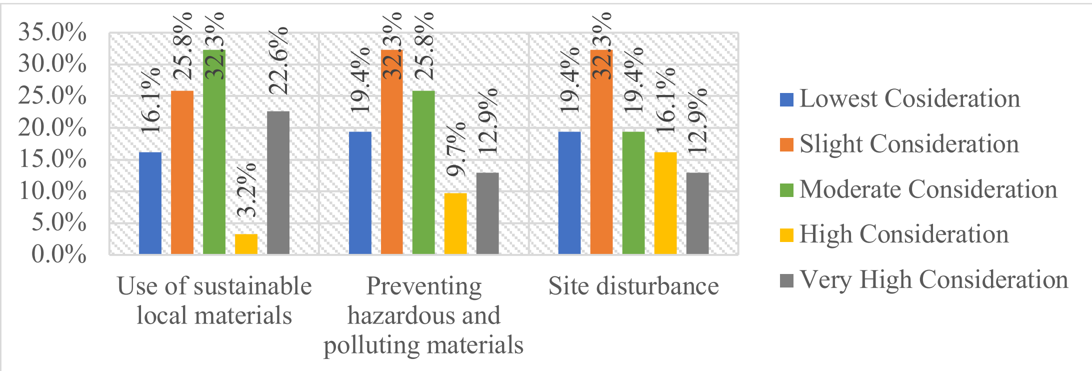


Figure 4.2.4:8 Sustainability; environmental dimension parameters.
Source: Field survey (2021).

Table 4.2.4:8 Descriptive statistics for sustainability; environmental dimension.

Sustainability; environmental dimension parameters	N	Mean	Std. deviation
Use of sustainable local materials	31	2.903	1.3749

Site disturbance	31	2.710	1.3215
Preventing hazardous and polluting materials	31	2.645	1.2793

Source: Field survey (2021).

ix) Sustainability; social dimension

The parameters assessed were: awareness & public participation; health, safety & wellbeing in the built forms; and jobs created with prefabrication. Figure 4.2.4:9 and Table 4.2.4:9 show the respondents' levels of consideration. Awareness & public participation had the highest mean of 2.968 (moderate consideration) with a low SD of 1.4020 while jobs created with prefabrication had the lowest mean of 2.323 with SD of 1.2217.

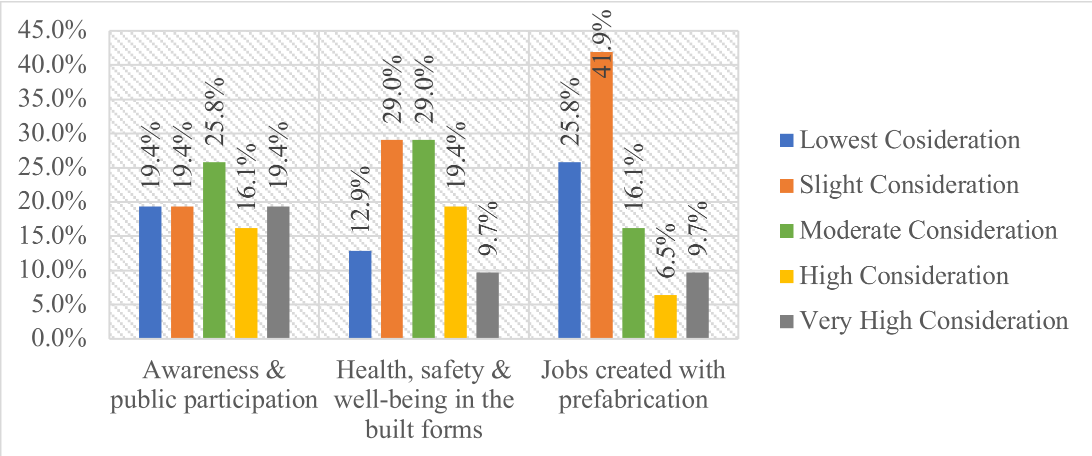


Figure 4.2.4:9 Sustainability; social dimension parameters.
Source: Field survey (2021).

Table 4.2.4:9 Descriptive statistics for sustainability; social dimension parameters.

Sustainability; social dimension parameters	N	Mean	Std. deviation
Awareness & public participation	31	2.968	1.4020
Jobs created with prefabrication	31	2.323	1.2217
Health, safety & wellbeing in the built forms	31	2.839	1.1859

Source: Field survey (2021).

x) Sustainability; cultural dimension

The parameters assessed were: aesthetics (culturally responsive built forms); and promotion of local materials & building techniques. Figure 4.2.4:10 and Table 4.2.4:10 show the respondents' levels of consideration. Aesthetics (culturally responsive built forms) had the highest mean of 2.613 (moderate consideration) with a low SD of 1.3084 while promotion of local materials & building techniques had the lower mean of 2.516 with SD of 1.1216.

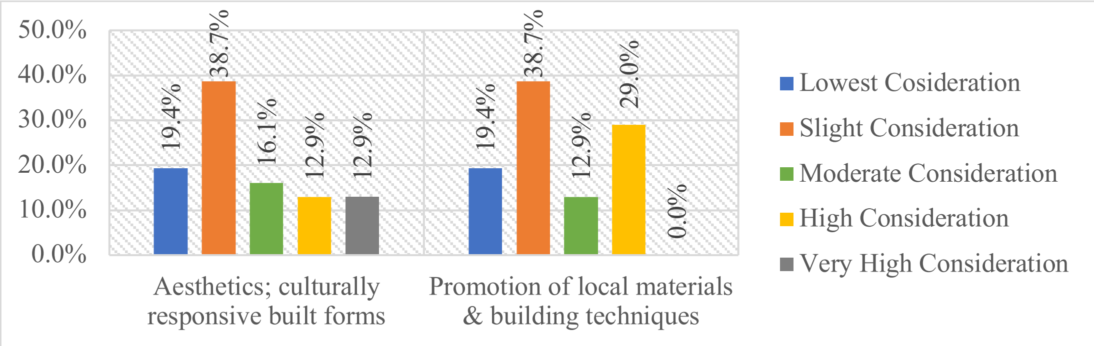


Figure 4.2.4:10 Sustainability; cultural dimension parameters.
Source: Field survey (2021).

Table 4.2.4:10 Descriptive statistics for sustainability; cultural dimension.

Sustainability; cultural dimension parameters	N	Mean	Std. deviation
Aesthetics; culturally responsive built forms	31	2.613	1.3084
Promotion of local materials & building techniques	31	2.516	1.1216

Source: Field survey (2021).

xi) Sustainability; economic dimension

The parameters assessed were: affordability on construction costs; and post-occupancy operations. Figure 4.2.4:11 and Table 4.2.4:11 show the respondents' levels of consideration. Affordability on construction costs had the highest mean of 3.774 (high consideration) with a low SD of 1.2835 while post-occupancy operations had the lower mean of 2.806 with SD of 1.3018.

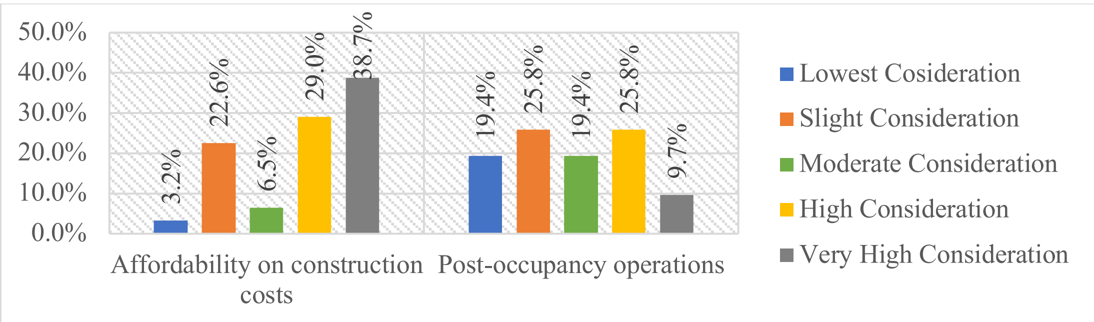


Figure 4.2.4:11 Sustainability; economic dimension parameters.
Source: Field survey (2021).

Table 4.2.4:11 Descriptive statistics for sustainability; economic dimension.

Sustainability; economic dimension parameters	N	Mean	Std. deviation
Post-occupancy operations	31	2.806	1.3018
Affordability on construction costs	31	3.774	1.2835

Source: Field survey (2021).

xii) Other parameters

The parameters assessed were: lack of awareness created; mindsets and perceptions; government projects not being executed using the OSM techniques; lack of research and development advancements; lack of retraining and reskilling labour force; lack of favorable government policy, incentives and promotion; lack of favorable building code and statutory approvals; lack of dissemination of current and less capital intensive OSM techniques. Figure 4.2.4:12 and Table 4.2.4:12 show the respondents' levels of consideration. Lack of dissemination of current and less capital intensive OSM techniques had the highest mean of 3.516 (high consideration) with a SD of 1.5027 while government projects not being executed using the OSM techniques had the lowest mean of 2.613 with SD of 1.3336.

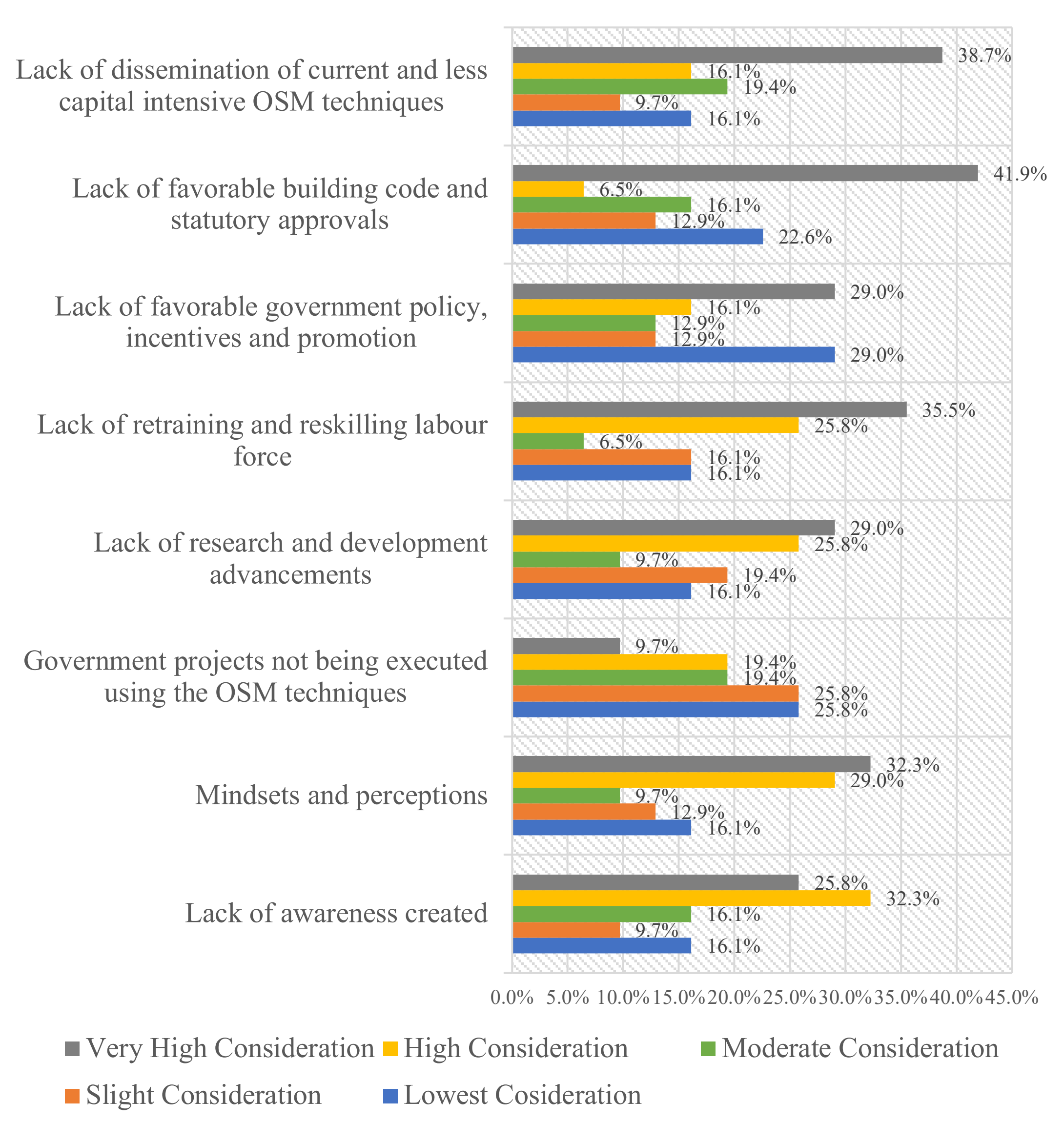


Figure 4.2.4:12 Other parameters that influence negatively.
Source: Field survey (2021).

Table 4.2.4:12 Descriptive statistics for other parameters.

Other parameters	N	Mean	Std. deviation
Lack of favorable building code and statutory approvals	31	3.323	1.6611
Lack of favorable government policy, incentives and promotion	31	3.032	1.6428
Lack of retraining and reskilling labour force	31	3.484	1.5247
Lack of dissemination of current and less capital intensive OSM techniques	31	3.516	1.5027
Lack of research and development advancements	31	3.323	1.4919
Mindsets and perceptions	31	3.484	1.4803
Lack of awareness created	31	3.419	1.4089
Government projects not being executed using the OSM techniques	31	2.613	1.3336

Source: Field survey (2021).

4.2.5 Parameters to Consider

How the parameters need to be considered in the decision-making to use OSM concrete building elements

Respondents were asked how the variables/parameters (cost; schedule/time; labour and productivity; scope; quality, predictability and reliability; risk; research and development; sustainability – environmental, social, cultural and economic dimensions; and other parameters in their opinion) need to be considered in the decision-making to use offsite manufacturing of concrete building elements in building construction projects in Nairobi. The consideration level scoring for this was done using a 5-point likert scale, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high consideration, 5 = very high consideration. Below is the report on findings as captured from the survey. The figures and tables under each variable in this section shows how the respondents responded on how the different parameters under each variable needs to be considered in the decision-making to use OSM concrete building elements.

i) Cost

The parameters assessed were: initial capital costs (fabrication facility costs); upfront design fees costs; material, labour, and time costs; transportation costs & craneage; and lifecycle costs. Figure 4.2.5:1 and Table 4.2.5:1 show the respondents' levels of consideration. Transportation costs & craneage had the highest mean of 4.203 (very high consideration) with the lowest standard deviation (SD) of 1.0787 while upfront design fees costs had the lowest mean of 3.405 with SD of 1.3542.

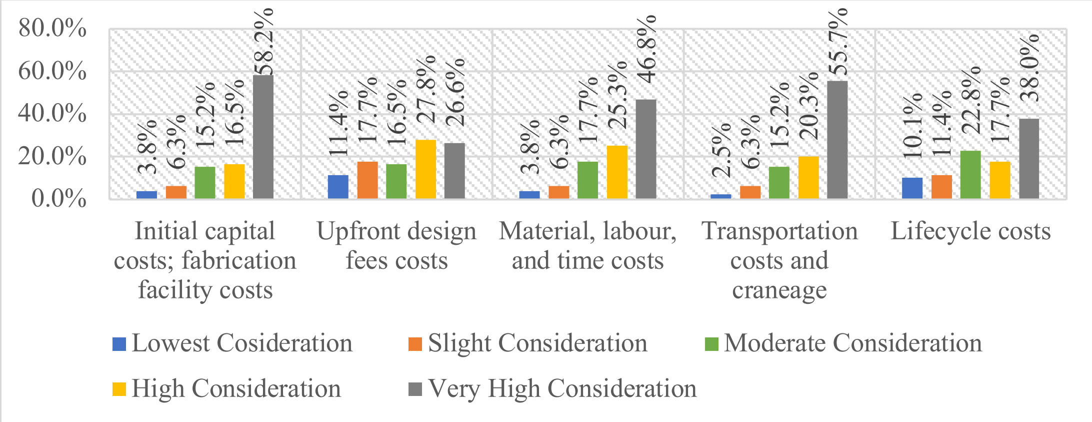


Figure 4.2.5:1 Cost parameters.
Source: Field survey (2021).

Table 4.2.5:1 Descriptive statistics for cost parameters.

Cost parameters	**N**	**Mean**	**Std. deviation**
Lifecycle costs	79	3.620	1.3616
Upfront design fees costs	79	3.405	1.3542
Initial capital costs; fabrication facility costs	79	4.190	1.1444
Material, labour, and time costs	79	4.051	1.1197
Transportation costs and craneage	79	4.203	1.0787

Source: Field survey (2021).

ii) Schedule/time

The parameters assessed were: delivery duration; and installation duration (sequencing & overlap). Figure 4.2.5:2 and Table 4.2.5:2 show the respondents' levels of consideration. Delivery duration had the highest mean of 4.342 (very high consideration) with the lowest SD of 0.9458 while installation duration (sequencing & overlap) had the lower mean of 4.278 with SD of 0.9992.

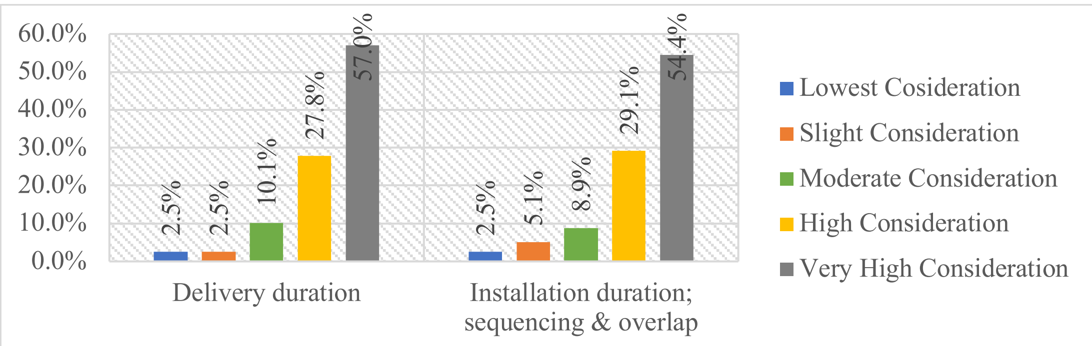


Figure 4.2.5:2 Schedule/time parameters.
Source: Field survey (2021).

Table 4.2.5:2 Descriptive statistics for schedule/time parameters.

Schedule/time parameters	N	Mean	Std. deviation
Installation duration; sequencing & overlap	79	4.278	0.9992
Delivery duration	79	4.342	0.9458

Source: Field survey (2021).

iii) Labour and productivity

The parameters assessed were: skilled/unskilled; prefabrication technology technical know-how/knowledge; training; and mindset/perception of productivity efficiency. Figure 4.2.5:3 and Table 4.2.5:3 show the respondents' levels of consideration. Prefabrication technology technical know-how/knowledge had the highest mean of 4.203 (very high consideration) with the lowest SD of 1.0175 while mindset/perception of productivity efficiency had the lowest mean of 3.684 with SD of 1.2765.

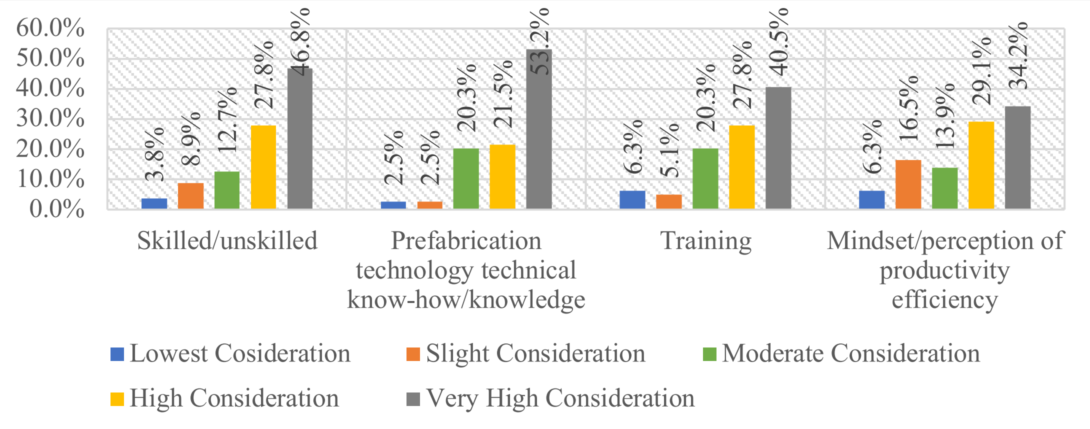


Figure 4.2.5:3 Labour and productivity parameters.
Source: Field survey (2021).

Table 4.2.5:3 Descriptive statistics for labour and productivity parameters.

Labour and productivity parameters	N	Mean	Std. deviation
Mindset/perception of productivity efficiency	79	3.684	1.2765
Training	79	3.911	1.1788
Skilled/unskilled	79	4.051	1.1424
Prefabrication technology technical know-how/knowledge	79	4.203	1.0175

Source: Field survey (2021).

iv) Scope

The parameters assessed were: complexity/extent of project; integration of design team & construction team; and supply chain management. Figure 4.2.5:4 and Table

4.2.5:4 show the respondents' levels of consideration. Integration of design team & construction team and complexity/extent of project both had the highest mean of 4.063 (very high consideration), though complexity/extent of project the lowest SD of 1.0663 while supply chain management had the lowest mean of 3.936 with SD of 1.1321.

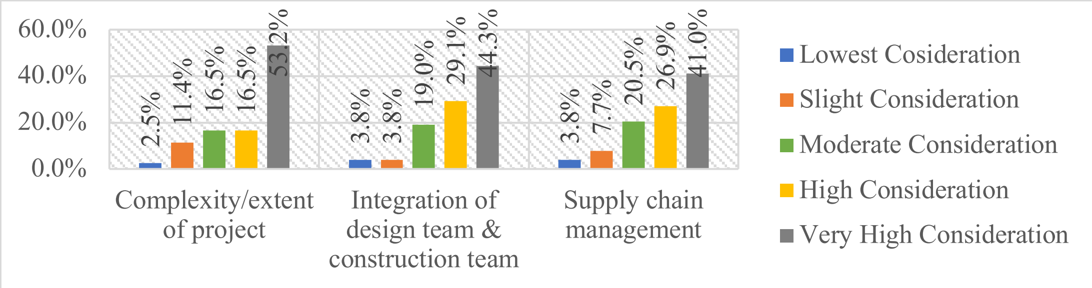


Figure 4.2.5:4 Scope parameters.
Source: Field survey (2021).

Table 4.2.5:4 Descriptive statistics for scope parameters.

Scope parameters	N	Mean	Std. deviation
Complexity/extent of project	79	4.063	1.1804
Supply chain management	78	3.936	1.1321
Integration of design team & construction team	79	4.063	1.0663

Source: Field survey (2021).

v) Quality, predictability and reliability

The parameters assessed were: workmanship; achieving specifications issued, by production & products quality and design quality; and durability. Figure 4.2.5:5 and Table 4.2.5:5 show the respondents' levels of consideration. Workmanship had the highest mean of 4.468 (very high consideration) with the lowest SD of 0.8892 while durability had the lowest mean of 4.266 with SD of 1.0826.

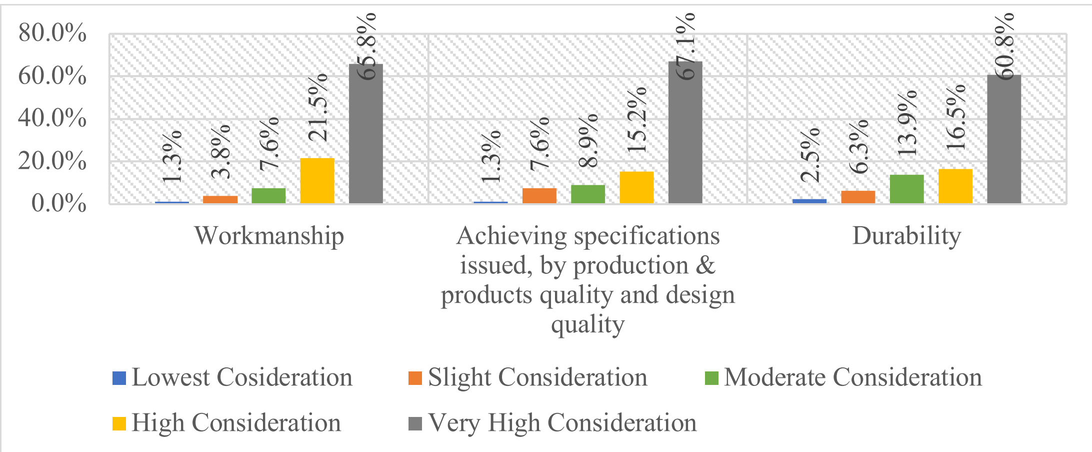


Figure 4.2.5:5 Quality, predictability and reliability parameters.
Source: Field survey (2021).

Table 4.2.5:5 Descriptive statistics for quality, predictability & reliability.

Quality, predictability and reliability parameters	N	Mean	Std. deviation
Durability	79	4.266	1.0826
Achieving specifications issued, by production & products quality and design quality	79	4.392	1.0180
Workmanship	79	4.468	0.8892

Source: Field survey (2021).

vi) Risk

The parameters assessed were: quality (unverified fabricators); financial vulnerability to clients, designers and contractors; safety and health (exposure to hazards); and extended producer responsibility (EPR). Figure 4.2.5:6 and Table 4.2.5:6 show the respondents' levels of consideration. Quality (unverified fabricators) had the highest mean of 4.278 (very high consideration) with a low SD of 1.0614 while financial vulnerability to clients, designers and contractors had the lowest mean of 3.924 with the lowest SD of 1.0349.

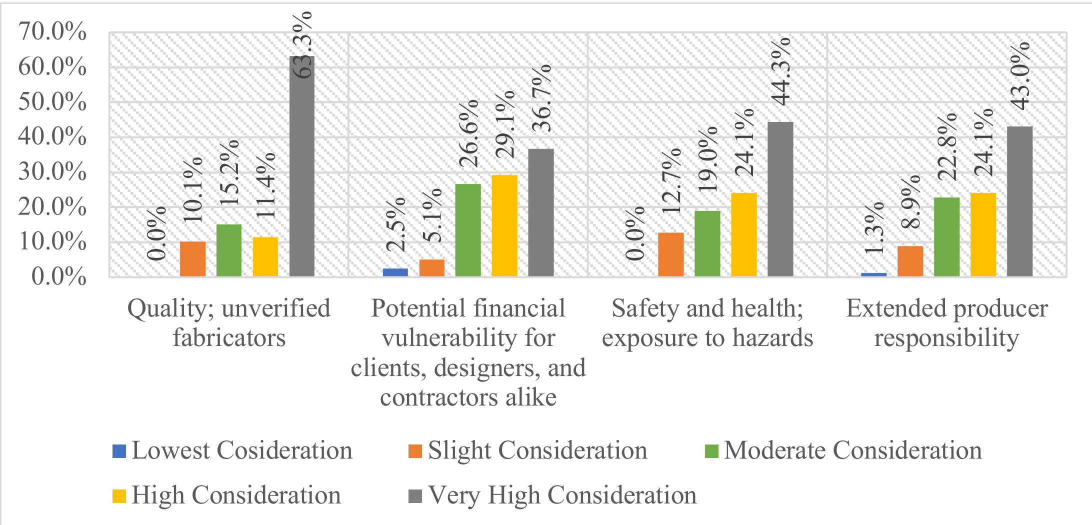


Figure 4.2.5:6 Risk parameters.
Source: Field survey (2021).

Table 4.2.5:6 Descriptive statistics for risk parameters.

Risk parameters	N	Mean	Std. deviation
Safety and health; exposure to hazards	79	4.000	1.0742
Extended producer responsibility	79	3.987	1.0681
Quality; unverified fabricators	79	4.278	1.0614
Financial vulnerability to clients, designers and contractors	79	3.924	1.0349

Source: Field survey (2021).

vii) Research and development

The parameters assessed were: contractor design-assist delivery; and cost cutting strategies. Figure 4.2.5:7 and Table 4.2.5:7 show the respondents' levels of consideration. Cost cutting strategies had the highest mean of 4.241 (very high consideration) with the lowest SD of 0.9366 while contractor design-assist delivery had the lower mean of 4.063 with SD of 0.9915.

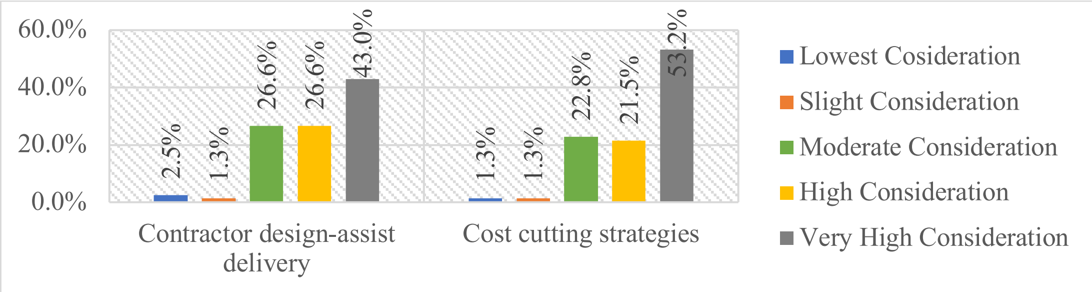


Figure 4.2.5:7 Research and development parameters.
Source: Field survey (2021).

Table 4.2.5:7 Descriptive statistics for research and development parameters.

Research and development parameters	N	Mean	Std. deviation
Contractor design-assist delivery	79	4.063	0.9915
Cost cutting strategies	79	4.241	0.9366

Source: Field survey (2021).

viii) Sustainability; environmental dimension

The parameters assessed were: use of sustainable local materials; preventing hazardous and polluting materials; and site disturbance. Figure 4.2.5:8 and Table 4.2.5:8 show the respondents' levels of consideration. Use of sustainable local materials had the highest mean of 4.253 (very high consideration) with the lowest SD of 0.9802 while site disturbance had the lowest mean of 3.772 with SD of 1.1541.

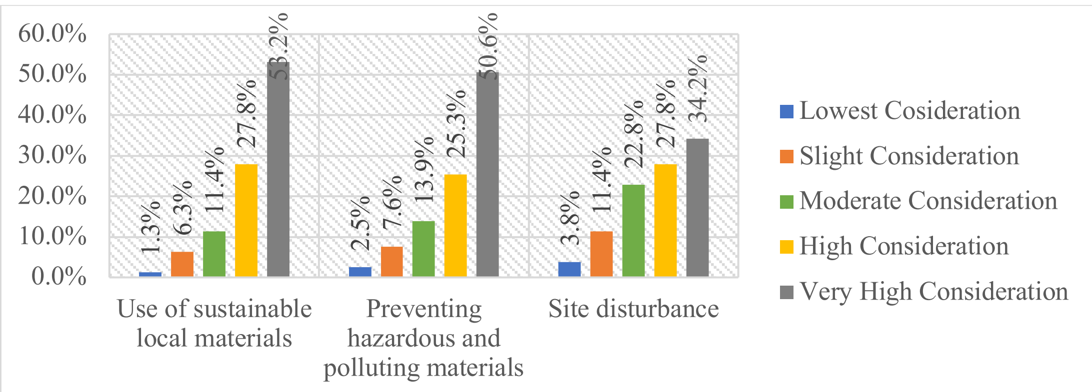


Figure 4.2.5:8 Sustainability; environmental dimension parameters.
Source: Field survey (2021).

Table 4.2.5:8 Descriptive statistics for sustainability; environmental dimension.

Sustainability; environmental dimension parameters	N	Mean	Std. deviation
Site disturbance	79	3.772	1.1541
Preventing hazardous and polluting materials	79	4.139	1.0829
Use of sustainable local materials	79	4.253	0.9802

Source: Field survey (2021).

ix) Sustainability; social dimension

The parameters assessed were: awareness & public participation; health, safety & wellbeing in the built forms; and jobs created with prefabrication. Figure 4.2.5:9 and Table 4.2.5:9 show the respondents' levels of consideration. Health, safety & wellbeing in the built forms had the highest mean of 4.051 (very high consideration) with the lowest SD of 0.9987 while awareness & public participation had the lowest mean of 3.747 with SD of 1.1818.

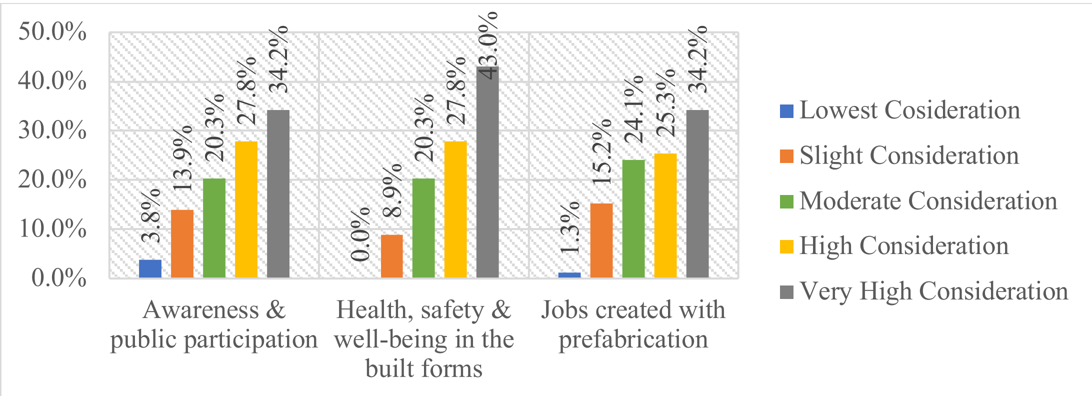


Figure 4.2.5:9 Sustainability; social dimension parameters.
Source: Field survey (2021).

Table 4.2.5:9 Descriptive statistics for sustainability; social dimension parameters.

Sustainability; social dimension parameters	N	Mean	Std. deviation
Awareness & public participation	79	3.747	1.1818
Jobs created with prefabrication	79	3.759	1.1234
Health, safety & wellbeing in the built forms	79	4.051	0.9987

Source: Field survey (2021).

x) Sustainability; cultural dimension

The parameters assessed were: aesthetics (culturally responsive built forms); and promotion of local materials & building techniques. Figure 4.2.5:10 and Table 4.2.5:10 show the respondents' levels of consideration. Promotion of local materials & building techniques had the highest mean of 3.848 (high consideration) with the lowest SD of

1.1219 while aesthetics (culturally responsive built forms) had the lower mean of 3.772 with SD of 1.2501.

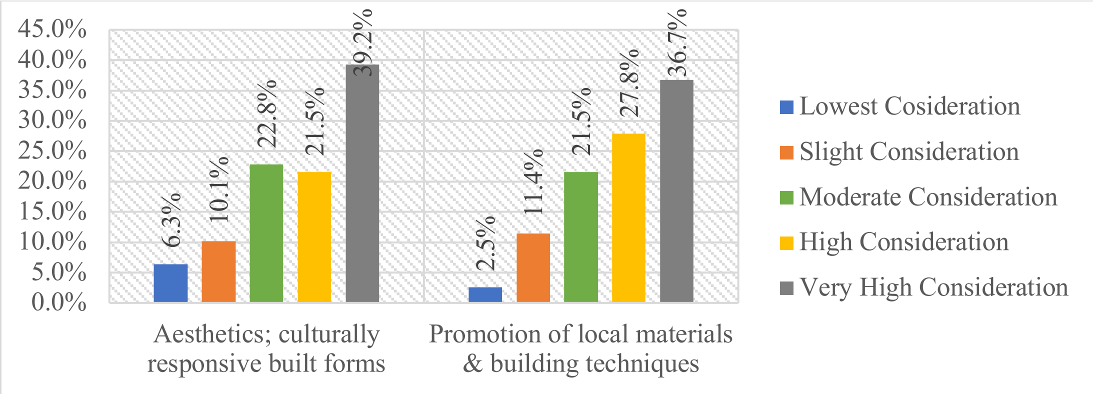


Figure 4.2.5:10 Sustainability; cultural dimension parameters.
Source: Field survey (2021).

Table 4.2.5:10 Descriptive statistics for sustainability; cultural dimension.

Sustainability; cultural dimension parameters	N	Mean	Std. deviation
Aesthetics; culturally responsive built forms	79	3.772	1.2501
Promotion of local materials & building techniques	79	3.848	1.1219

Source: Field survey (2021).

xi) Sustainability; economic dimension

The parameters assessed were: affordability on construction costs; and post-occupancy operations. Figure 4.2.5:11 and Table 4.2.5:11 show the respondents' levels of consideration. Affordability on construction costs had the highest mean of 4.481 (very high consideration) with the lowest SD of 0.7984 while post-occupancy operations had the lower mean of 4.013 with SD of 1.0063.

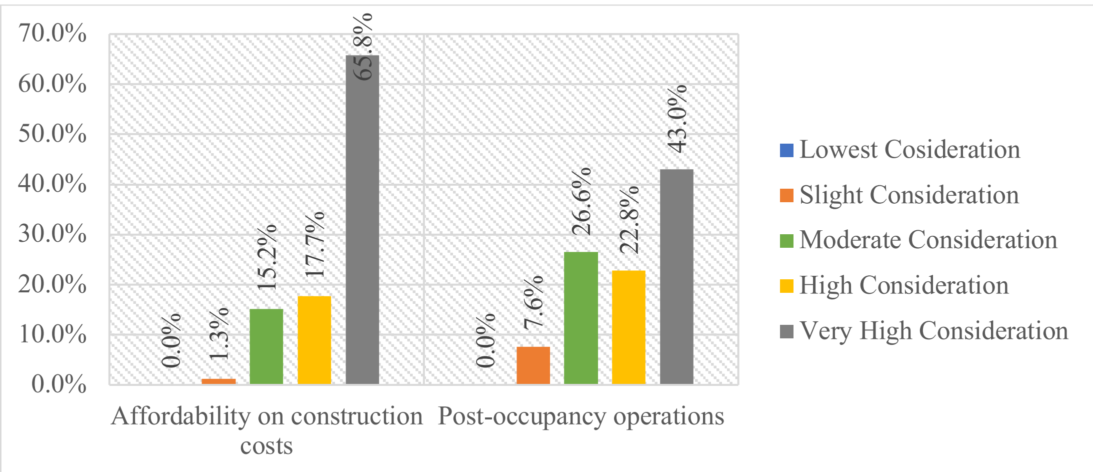


Figure 4.2.5:11 Sustainability; economic dimension parameters.
Source: Field survey (2021).

Table 4.2.5:11 Descriptive statistics for sustainability; economic dimension.

Sustainability; economic dimension parameters	N	Mean	Std. deviation
Post-occupancy operations	79	4.013	1.0063
Affordability on construction costs	79	4.481	0.7984

Source: Field survey (2021).

xii) Other parameters

The parameters assessed were: procurement strategy; interface management; interface between each element and between the teams; design implications (dimensional coordination & module size, design redundancy etc.); IT advances and effect on OSM (CAD, BIM); pre-installation trial assemblies or prototypes; transportation, craneage and installation; optimising and organising onsite work; retraining and reskilling; taxation subsidies on materials; research and development advancements; retrained and reskilled labour force; government policy, incentives and promotion; building code and statutory approvals; and current and less capital intensive OSM techniques. Figure 4.2.5:12 and Table 4.2.5:12 show the respondents' levels of consideration. Design implications (dimensional coordination & module size, design redundancy etc.) had the highest mean of 4.190 (very high consideration) with the lowest SD of 0.9618 while taxation subsidies on materials had the lowest mean of 3.532 with the highest SD of 1.3285.

Table 4.2.5:12 Descriptive statistics for other parameters.

Other parameters	N	Mean	Std. deviation
Taxation subsidies on materials	79	3.532	1.3285
Government policy, incentives and promotion	79	3.835	1.2344
Pre-installation trial assemblies or prototypes	79	3.747	1.1488
Building code and statutory approvals	79	3.975	1.1320
Research and development advancements	79	4.089	1.0883
Transportation, craneage and installation	79	4.101	1.0812
Retrained and reskilled labour force	79	4.025	1.0739
Optimising and organising onsite work	79	4.013	1.0681
IT advances and effect on offsite manufacturing; CAD, BIM	79	3.747	1.0678
Current and less capital intensive OSM techniques	79	4.000	1.0500
Interface management; interface between each element and between the teams	79	3.987	1.0438

Procurement strategy	79	3.987	1.0190
Retraining and reskilling	79	3.861	0.9836
Design implications; dimensional coordination & module size, design redundancy etc.	79	4.190	0.9618

Source: Field survey (2021).

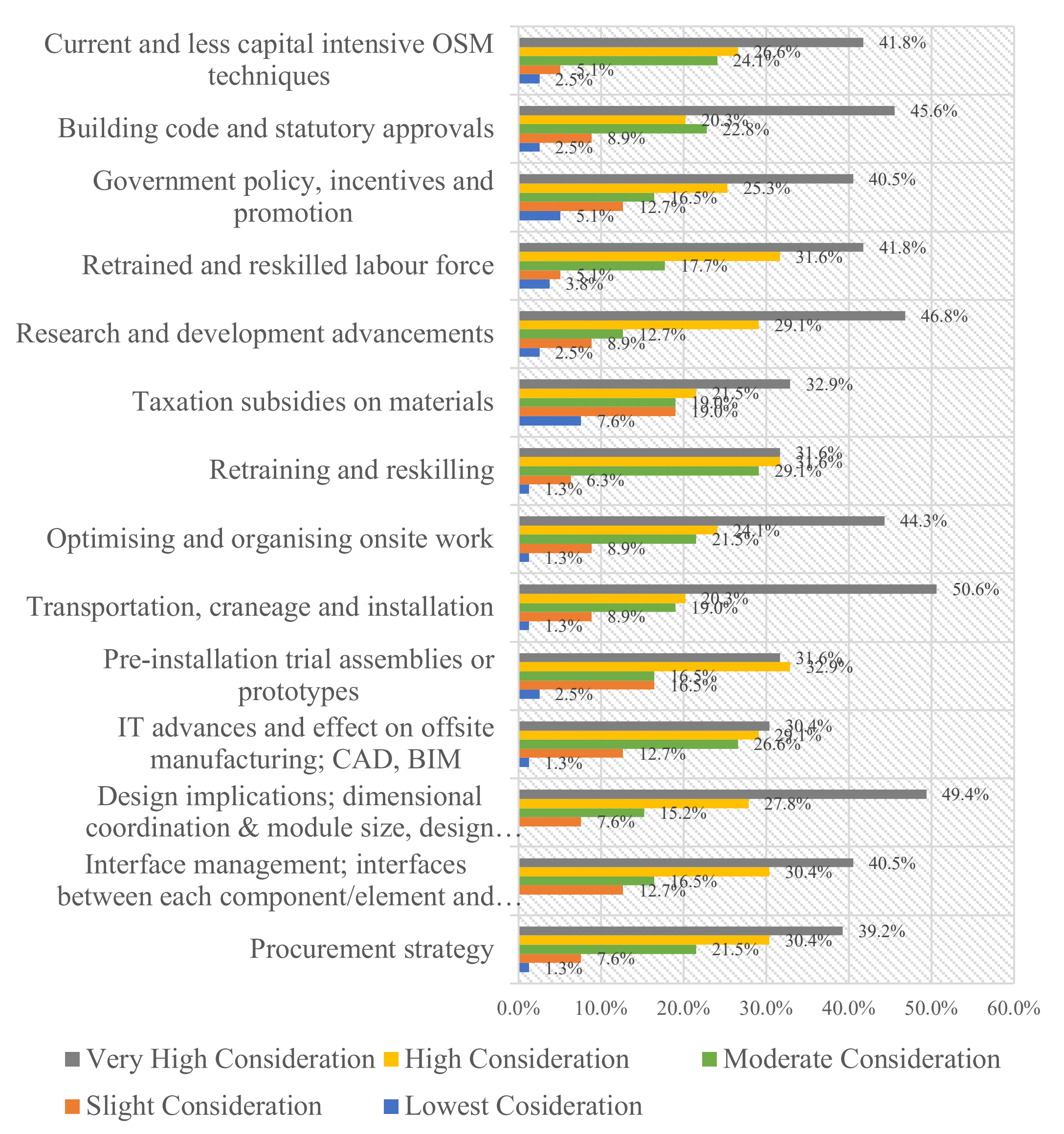


Figure 4.2.5:12 Other parameters that need considered.
Source: Field survey (2021).

4.2.6 Strategies to Increase the Use of OSM Concrete Building Elements

Respondents were asked how the strategies as listed below (and other appropriate strategies in their opinion) can be implemented to increase the use of offsite manufacturing of concrete building elements in building construction projects in Nairobi. The consideration level scoring for this was done using a 5-point likert scale, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high consideration, 5 = very high consideration. Below is the report on findings as captured from the survey.

The parameters assessed were: taxation subsidies on materials; creating awareness to the public; incorporating content in curriculum of higher learning institutions; executing some government projects using the techniques; research and development advancements; retraining and reskilling of labour force; reviewing government policy, incentives and promotion; reviewing building code and statutory approvals; and dissemination of current and less capital intensive OSM techniques. Figure 4.2.6:1 and Table 4.2.6:1 show the respondents' levels of consideration. Design implications (dimensional coordination & module size, design redundancy etc.) had the highest mean of 4.190 (very high consideration) with the lowest SD of 0.9618 while taxation subsidies on materials had the lowest mean of 3.532 with the highest SD of 1.3285.

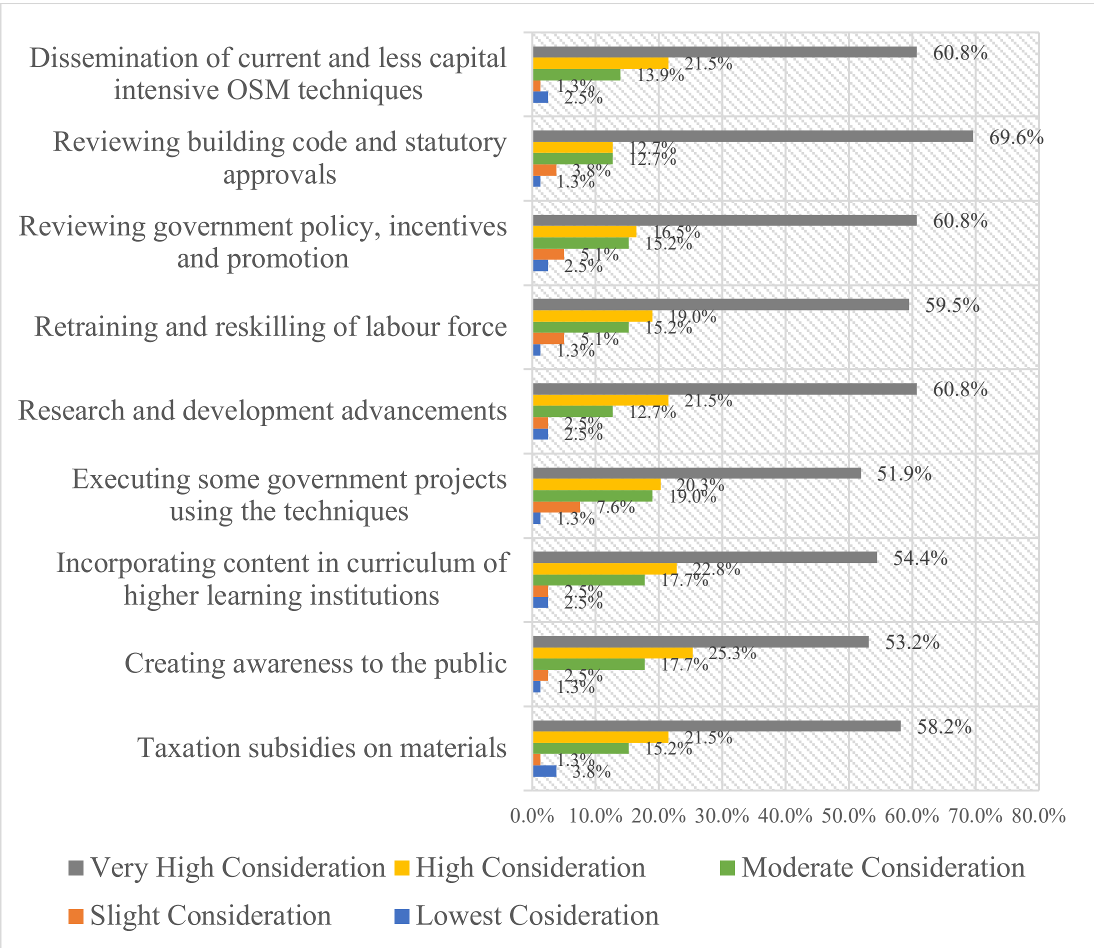


Figure 4.2.6:1 Appropriate strategies.
Source: Field survey (2021).

Table 4.2.6:1 Descriptive statistics for appropriate strategies.

Strategies	N	Mean	Std. deviation
Reviewing government policy, incentives and promotion	79	4.278	1.0614
Executing some government projects using the techniques	79	4.139	1.0590
Taxation subsidies on materials	79	4.291	1.0272
Incorporating content in curriculum of higher learning institutions	79	4.241	1.0028
Retraining and reskilling of labour force	79	4.304	0.9917
Research and development advancements	79	4.354	0.9745
Dissemination of current and less capital intensive OSM techniques	79	4.367	0.9497
Reviewing building code and statutory approvals	79	4.456	0.9446
Creating awareness to the public	79	4.266	0.9297

Source: Field survey (2021).

4.2.7 Inferential Statistics

Below are the reliability statistics across the four thematic areas of parameters that influenced positively; negatively; parameters that need to be considered; and appropriate strategies that can be implemented to increase the use of OSM concrete building elements. The Cronbach's alpha measure of internal consistency was used to check the reliability statistics as shown in Tables 4.2.7:1-4. Reliability test of the several items in the questionnaire ranged from 91.0% to 96.3% averaging at 93.1% for the four thematic areas, indicating a high internal consistency and hence reliability.

i) Positive influence reliability statistics

Table 4.2.7:1 Positive influence reliability statistics.

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.927	.928	40

Source: Field survey (2021).

ii) Negative influence reliability statistics

Table 4.2.7:2 Negative influence reliability statistics.

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.910	.910	41

Source: Field survey (2021).

iii) Parameters to consider reliability statistics

Table 4.2.7:3 Parameters to consider reliability statistics.

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.962	.963	47

Source: Field survey (2021).

iv) Strategies to increase the use reliability statistics

Table 4.2.7:4 Appropriate strategies reliability statistics.

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.923	.923	9

Source: Field survey (2021).

4.2.8 Serendipitous Findings

These are relevant matters which though not part of the study, are uncovered in the course of investigation. Some of the serendipitous findings include:

i. Matters of site safety and health at some of the offsite manufacturing/fabrication facilities visited are not fully complied with. This can in turn leads to inefficiencies and ineffectiveness of the labour force; and work-related musculoskeletal disorders (MSD). A study can probably be done to assess how the incompliance of standard health and safety regulations affect productivity. Figure 4.2.9:1 shows an operator without any safety gear captured in one of the OSM fabrication facilities.

Figure 4.2.8:1 An offsite fabrication facility for wall panels.
Source: Author (2021).

To note are the working conditions without proper safety signs and gear.

ii. There are relatively few OSM concrete building elements manufacturers in Nairobi for developers to source the elements/products from in case the developers are not setting up a fabrication facility for their projects due to the high costs of setting up one. This could be attributed by the lack of mass acceptance of the offsite manufacturing techniques and other alternative building materials and technologies.
iii. The question of sustainability of concrete as a building construction material, which is tied to the carbon dioxide (CO_2) emissions into the atmosphere during cement production. Heavy investment into research and development on this needs to be done to find more sustainable ways of using/making concrete.

4.3 Discussion of Findings

4.3.1 Usage of OSM Concrete Building Elements

Data collected from the survey reveal that only the non-volumetric type of offsite manufacturing of concrete building elements is used in building construction projects in Nairobi. These OSM concrete building elements used include (in the order of most used to least): precast slabs; precast wall panels (load /non-load bearing); other precast concrete elements/products (window sills, wall copings, concrete balusters/railings, paving slabs/blocks); precast beams; precast concrete façade panels/claddings; precast columns; precast staircases; precast concrete girders; precast foundation footings; precast glass fiber reinforced concrete façade panels/cladding; precast concrete roofs; and precast foundation piles.

The deduction from this can be that the usage of offsite manufacturing of concrete building elements has not progressed as much in building construction projects in Nairobi. Part of this study was to establish the appropriate strategies that can be implemented to increase the use of OSM concrete building elements in building construction projects in Nairobi. These strategies are reviewed and collated in the literature review, and the findings from the respondents' point of view reported under item 4.2.6 and discussed under item 4.3.5.

4.3.2 Positive Influence

How the parameters influenced positively the decision to use OSM concrete building elements

i) Cost

The parameters assessed were: material, labour, and time costs (had highest mean - high consideration); initial capital costs (fabrication facility costs); upfront design fees costs (had lowest mean - moderate consideration); transportation costs & craneage; and lifecycle costs. Figure 4.2.3:1 and Table 4.2.3:1 show detailed statistics.

Smith (2010) notes that OSM has been promoted as being more cost-effective than other on-site methods of construction, owing to the fact that cost is comprised of three major factors for which OSM has conceptual solutions: labour, material, and time. This therefore can attribute to the material, labour and time costs parameter having the highest consideration of the cost parameters.

Initial capital costs (fabrication facility costs); upfront design fees costs; and increased transportation costs & craneage are additional costs incurred with offsite manufacturing. These therefore cannot be considered highly as parameters that influenced positively the decision to use OSM concrete building elements. Lifecycle costs had the second highest mean of 3.170 (high consideration) with a low SD of 1.3565. It can be adduced that prefabrication is a lifecycle investment, with chances of higher initial capital costs, but better long-term value.

The Figure 4.3.2:1-2 shows an OSM facility for precast beams, for floor slabs.

Figure 4.3.2:1 Precast beams OSM facility.
Source: Author (2021).

Depending with a project's scope & economies of scale, developers could opt to set up such a facility, or buy OSM concrete building elements from such manufacturers.

Figure 4.3.2:2 Precast beams transported to cure within the OSM facility.
Source: Author (2021).
Cranes are used for 225mm deep beams, 10m long due to high weight. A challenge in transport to a site is KeNHA weight limits for cargo.

ii) Schedule/time

The parameters assessed were: installation duration (sequencing & overlap) had the higher mean - very high consideration); and delivery duration (had lower mean, but very high consideration). The respondents considered delivery duration and installation duration (sequencing & overlap) very highly. Figure 4.2.3:4 and Table 4.2.3:2 show detailed statistics. Gibb (1999) notes that a reduction in onsite construction time is undoubtedly the most significant productivity advantage of prefabrication, attained through the overlapping of offsite and onsite tasks. This affirms the very high consideration as parameters that influenced positively the decision to use OSM concrete building elements.

iii) Labour and productivity

The parameters assessed were: skilled; prefabrication technology technical know-how/knowledge (had highest mean - high consideration); training (had lowest mean - high consideration); and mindset/perception of productivity efficiency. Figure 4.2.3:5 and Table 4.2.3:3 show detailed statistics. Smith (2010) notes that technical changes including machinery, evolutions in material science and digitally such as BIM have impacted positively labour productivity in construction. This can therefore be attributed to the respondents' high consideration of the same as parameters that influenced positively the decision to use OSM concrete building elements.

iv) Scope

The parameters assessed were: complexity/extent of project (had highest mean - high consideration); integration of the design team and the construction team; and supply chain management (had lowest mean - high consideration). The differences in the means and standard deviations (SD) of the 3 parameters are minimal and can be generalized that they are all highly considered. Figure 4.2.3:6 and Table 4.2.3:4 show detailed statistics. Gibb (1999) notes that as the breadth, size, complexity of a project increases, so do integration, coordination, and requirements for earlier OSM decision making before construction starts. Smith (2010) notes also that OSM enables contractors to more effectively oversee the integration of SCM by utilizing digital tools to increase quality, reduce costs and regulate the greenness of materials.

v) Quality, predictability and reliability

The parameters assessed were: workmanship (had highest mean - very high consideration); achieving specifications issued, by production & products quality and design quality; and durability (had lowest mean - high consideration). Workmanship; and achieving specifications issued, by production & products quality and design quality were considered very highly while durability was considered highly. Figure 4.2.3:7 and Table 4.2.3:5 show detailed statistics. Gibb (1999) notes that an OSM facility environment is much more conducive to manufacturing higher quality products. (Smith 2010) also notes that OSM facilities use automation and precise methods of production and for this, product warranties are more substantial from the OSM facilities. This adduces to the high to very high consideration given for these parameters.

vi) Risk

The parameters assessed were: safety and health (exposure to hazards) had highest mean - high consideration; quality (unverified fabricators); financial vulnerability to clients, designers and contractors; and extended producer responsibility (had lowest mean - high consideration). Figure 4.2.3:8 and Table 4.2.3:6 show detailed statistics. Gibb (1999) notes that OSM lowers the amount of work done onsite, and hence lowers the exposure to hazards. This would attribute to safety and health (exposure to hazards) having the highest consideration as a parameter that influenced positively the decision to use OSM. The other three parameters also have high considerations.

Gibb (1999) notes that enhanced planning involved in prefabrication provides an opportunity for suitable assessment of risk to be done. This could help interpret the high considerations as appropriate risk assessment and mitigation. Was done and considered by the respondents.

vii) Research and development

The parameters assessed were: cost cutting strategies (had higher mean - very high consideration); and contractor design-assist delivery (had lower mean - high consideration). Figure 4.2.3:9 and Table 4.2.3:7 show detailed statistics. Smith (2010) notes that OSM enables the fabricator to participate the tendering process or collaborate with the design and construction teams early in a design-assist delivery to evaluate costing and bring the design to a constructible and affordable balance.

viii) Sustainability; environmental dimension

The parameters assessed were: site disturbance (had highest mean - high consideration); use of sustainable local materials; and preventing hazardous and polluting materials (had lowest mean - high consideration). All the parameters had high consideration. Figure 4.2.3:10 and Table 4.2.3:8 show detailed statistics. Gibb (1999) notes OSM helps reduce site disturbance, material wastage, noise, dust, better controls on atmospheric pollution, and is easier to recycle materials and supplies. Smith (2010) notes that the the embodied energy in materials is one of the considerations for energy consumption of a building. Use of local materials leads to low embodied energy and therefore can be attributed to the high consideration as a parameter that influenced positively the use of OSM. This, amongst other as discussed in literature review, attributes to the high consideration given to these environmental dimension parameters of sustainability.

ix) Sustainability; social dimension

The parameters assessed were: awareness & public participation (had lowest mean - moderate consideration); health, safety & wellbeing in the built forms (had highest mean - high consideration); and jobs created with prefabrication (high consideration). Figure 4.2.3:11 and Table 4.2.3:9 show detailed statistics. Awareness & public participation had moderate consideration implying it's not considered highly as a parameter that influenced positively the decision to use OSM. Hawken, Lovins and Lovins (2010) notes that the AEC sector must review sustainability from the point of view of natural and human capital; the triple bottom line of sustainability, which include society, environment and economics.

x) Sustainability; cultural dimension

The parameters assessed were: aesthetics (culturally responsive built forms) had higher mean; and promotion of local materials & building techniques (had lower mean). All the parameters had high consideration. Figure 4.2.3:12 and Table 4.2.3:10 show detailed statistics. Sustainability as a concept and cultural definition, is similar to minimizing environmental degradation and encroachment.

xi) Sustainability; economic dimension

The parameters assessed were: affordability on construction costs (had higher mean); and post-occupancy operations (had lower mean). All the parameters had high consideration. Figure 4.2.3:13 and Table 4.2.3:11 show detailed statistics. Smith (2010) notes that OSM can be used to improve construction sustainability considering the entire lifecycle of a facility. Cumulatively, the parameters discussed under sustainability lead to affordability on construction costs & post-occupancy operations.

xii) Other parameters

The parameters assessed were: awareness of the OSM techniques (had highest mean - high consideration); research and development advancements (high consideration); retrained and reskilled labour force (high consideration); current and less capital intensive OSM techniques disseminated (high consideration); favorable government policy, incentives and promotion (moderate consideration); favorable building code and statutory approvals (moderate consideration); and influence from government projects executed using the OSM techniques (had lowest mean - moderate consideration). Figure 4.2.3:14 and Table 4.2.3:12 show detailed statistics.

The 3no. parameters with moderate consideration are the ones in which the government and its regulatory authorities are the key players. This implies their policies, incentives and promotion towards influencing positively the use of OSM concrete building elements is low. Saggaff (2017) also notes that inadequate push factors from governments and policymakers, such as the public works department and local authorities influence negatively the use of OSM.

4.3.3 Negative Influence

How the parameters influenced negatively the decision to not use OSM concrete building elements

i) Cost

Transportation costs & craneage (had highest mean – very high consideration); initial capital costs - fabrication facility costs (high consideration); upfront design fees costs (moderate consideration); and lifecycle costs (lowest mean – moderate consideration). Figure 4.2.4:1 and Table 4.2.4:1 show detailed statistics. The three parameters are consistent with the discussion on cost parameters on the positive influence under item 4.3.2 (i). Smith (2010) notes that prefabrication may incur additional costs such as increased transport costs and craning/setting for large components; capital costs (such as fabrication facility costs) and lifecycle costs; manufacturing facilities overheads; and upfront design fee costs as OSM necessitates more coordination with the construction and manufacturing teams, hence designers (architects and engineers) could charge higher fees for the time investment.

Material, labour, and time costs parameter had high consideration, inconsistent with the discussion under item 4.3.2 (i). As had made reference to Smith (2010), material, labour, and time costs parameter is considered as a parameter that influences positively the decision to use OSM, and the expectation as a parameter that influenced negatively the decision to not use OSM, this parameter ought to have been considered relatively low compared to the others.

ii) Schedule/time

The parameters under schedule/time were all considered moderately. Figure 4.2.4:2 and Table 4.2.4:2 show detailed statistics. These results and considerations are consinstent with the discusion under item 4.2.3 (ii). Schedule/time is not a significant parameter influencing negatively the decision to not use OSM concrete building elements, the reverse is valid as per the findings from the study congruous with the literature.

iii) Labour and productivity

Prefabrication technology technical know-how/knowledge had highest mean (high consideration). All the parameters had high consideration. Figure 4.2.4:3 and Table

4.2.4:3 show detailed statistics. This is inconsinstent with the discusion under item 4.2.3 (iii). However, Blismas (2007) notes that clients' and industry professionals' lack of knowledge, including designers and contractors has a negative impact on their decision not to utilise OSM. Nawi, Lee and Nor (2011) also echo a similar sentiment that the negative influence on the decision to not utilise OSM revolves around skills and knowledge, client perceptions and perceptions of professionals. Saggaff (2017) also notes lack of technical knowledge from manufacturing to construction is an impediment.

iv) Scope

Complexity/extent of project parameters had highest mean (high consideration); integration of design team & construction team (high consideration); and supply chain management had lowest mean (moderate consideration). Figure 4.2.4:4 and Table 4.2.4:4 show detailed statistics. This is inconsistent with the discusion under item 4.3.2 (iv). However, Nawi, Lee and Nor (2011) note that the influence negatively on the decision to not use OSM revolves around project delivery and supply chains.

v) Quality, predictability and reliability

Workmanship had the highest mean (high consideration) while durability had the lowest mean of (moderate consideration). Figure 4.2.4:5 and Table 4.2.4:5 show detailed statistics. Achieving specifications issued, by production & products quality and design quality; and workmanship having high consideration is inconsistent with the discusion under item 4.3.2 (v). As had made reference to Gibb (1999), an OSM factory environment is more favourable to manufacturing higher quality products.

vi) Risk

Financial vulnerability to clients, designers and contractors had highest mean (high consideration) while safety and health (exposure to hazards) had lowest mean (moderate consideration) - being consistent with the discusion under item 4.3.2 (vi). Figure 4.2.4:6 and Table 4.2.4:6 show detailed statistics. Financial vulnerability to clients, designers and contractors; and quality (unverified fabricators) having high consideration is inconsistent with the discusion under item 4.3.2 (vi). However, risk relates to the exposure to the possibility of incurring losses and hazards at construction sites and other project related risks. From the results, it can be adduced that poor risk assessment and mitigation could result to these parameters influencing negatively the decision to not use OSM concrete building elements.

vii) Research and development

Cost cutting strategies had the highest mean (high consideration) while contractor design-assist delivery had the lower mean (high consideration). Figure 4.2.4:7 and Table 4.2.4:7 show detailed statistics. This is inconsistent with the discusion under item 4.3.2 (vii). As had made reference to Smith (2010), OSM allows the design and construction teams to have early coordination and integration in design-assist delivery to assess cost cutting strategies amongst others.

viii) Sustainability; environmental dimension

Use of sustainable local materials had highest mean (moderate consideration) with a while preventing hazardous and polluting materials had the lowest (moderate consideration). Figure 4.2.4:8 and Table 4.2.4:8 show detailed statistics. This is inconsistent with the discusion under item 4.3.2 (viii) implying sustainability (environmental dimension) is not as significant influencing negatively the decision to not use OSM concrete building elements.

ix) Sustainability; social dimension

Awareness & public participation had highest mean (moderate consideration) while jobs created with prefabrication had lowest mean (moderate consideration). Figure 4.2.4:9 and Table 4.2.4:9 show detailed statistics. Awareness & public participation had highest mean implies the parameter is more significant influence negatively in the decision making to not use OSM concrete building elements. The results are consistent with the discusion under item 4.3.2 (ix).

x) Sustainability; cultural dimension

Aesthetics (culturally responsive built forms) had higher mean (moderate consideration) while promotion of local materials & building techniques had lower mean (moderate consideration). Figure 4.2.4:10 and Table 4.2.4:10 show detailed statistics. The findings are consistent with the discusion under item 4.3.2 (x) implying they are not as significant influencing negatively the decision to not use OSM concrete building elements.

xi) Sustainability; economic dimension

Affordability on construction costs had the highest mean (high consideration) while post-occupancy operations had the lower mean (moderate consideration) - being consistent with the discusion under item 4.3.2 (xi). Figure 4.2.4:11 and Table 4.2.4:11 show detailed statistics. Affordability on construction costs having a high consideration is inconsistent with the discusion under item 4.3.2 (xi). However, it can be adduced that while assessing capital costs at the onset of a project can influencing negatively the decision to not use OSM concrete building elements. This is with the view of economies of scale and initial capital costs such as fabrication facility costs could amount to not relating proportionally with the scope of the project.

xii) Other parameters

The parameters assessed were: lack of dissemination of current and less capital intensive OSM techniques (had highest mean - high consideration); lack of awareness created (high consideration); mindsets and perceptions (high consideration); lack of research and development advancements (high consideration); lack of retraining and reskilling labour force (high consideration); lack of favorable government policy, incentives and promotion (high consideration); lack of favorable building code and statutory approvals (high consideration); and government projects not being executed using the OSM techniques (had lowest mean - moderate consideration). Figure 4.2.4:12 and Table 4.2.4:12 show detailed statistics.

From the results, the parameters are quite significant in influencing negatively the decision to not use OSM concrete building elements. Some supporting authors include: Nawi, Lee and Nor (2011) identify some of the factors that attribute to this, revolves around skills and knowledge, client and professionals perceptions, and lack of government policy, incentives and promotion. Blismas (2007) notes that lack of clients' and professionals' knowledge contributes to this. Gbadebo (2014) notes that dissemination of information to the public and "leadership by example" is needed of the public sector. Saggaff (2017) notes that there is inadequate push factors from governments and policymakers like public works department and local authorities.

From the results and discussion by the other authors, the parameters that influence negatively the decision to not use OSM concrete building elements are similar to those influencing Nairobi in a similar negative direction. This study also aimed to establish the appropriate strategies that can be implemented to increase the use of OSM concrete building elements in building construction projects in Nairobi and are reviewed, findings reported and discussed in several sections of the study.

4.3.4 Parameters to Consider

How the parameters need to be considered in the decision-making to use OSM concrete building elements

i) Cost

The parameters were considered very highly (3no.) to highly (2no.). Figure 4.2.5:1 and Table 4.2.5:1 show detailed statistics. This implies the cost parameters are important in the decision-making consideration to use OSM concrete building elements. The parameters are: initial capital costs (fabrication facility costs); upfront design fees costs; material, labour, and time costs; transportation costs & craneage; and lifecycle costs.

As much OSM has been popularized as being more cost-effective according to Smith (2010), Gibb (1999) notes the following should be factored when comparing OSM to on-site construction: potential extra costs (real costs of the OSM facility, extra costs from large transport capacity, extra costs from added site craneage capacity); and potential savings (OSM productivity cost savings, onsite cost savings from shorter period of construction, onsite cost savings arising from fewer onsite activities, onsite cost savings from reduced construction workers, cost savings from reduced transport, cost savings from more effective utilization of site craneage, cost savings from reduced unplanned onsite remedial tasks, changes to project cash flow).

ii) Schedule/time

All the parameters were considered very highly. Figure 4.2.5:2 and Table 4.2.5:2 show detailed statistics. This implies the schedule/time parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: delivery duration; and installation duration (sequencing & overlap). Gibb (1999) notes that the the use of OSM reduces project duration: leading to the client obtaining the facility at an earlier date; achieving the overlap of offsite and on-site activities which would be done in sequence using traditional methods instead.

iii) Labour and productivity

The parameters were considered very highly (2no.) to highly (2no.). Figure 4.2.5:3 and Table 4.2.5:3 show detailed statistics. This implies the labour and productivity parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: skilled/unskilled labour force; prefabrication technology technical know-how/knowledge; training; and mindset/perception of productivity efficiency. Smith (2010) notes that OSM technological advancements in machinery, physical manufacturing tools and prefabrication/equipment technology have influenced labour productivity and technical know-how/knowledge and training are amongst the factors to consider.

iv) Scope

The parameters were considered very highly (2no.) to highly (1no.). Figure 4.2.5:4 and Table 4.2.5:4 show detailed statistics. This implies the scope parameters are important in the decision-making consideration to utilize OSM concrete building elements. The parameters are: complexity/extent of project; integration of design team & construction team; and supply chain management. The breadth, size, complexity, and the involvement of individuals and teams (both design and construction) needed to finish a project undertaking are the key considerations while assessing scope. The integration of teams in both the earlier OSM decision making and design; and construction stages happen at both physical and organisational levels (Gibb 1999). OSM enables contractors to more effectively oversee supply chain management integration (Harland 1996).

v) Quality, predictability and reliability

All the parameters were considered very highly. Figure 4.2.5:5 and Table 4.2.5:5 show detailed statistics. This implies the quality, predictability and reliability parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: workmanship; achieving specifications issued, by production & products quality and design quality; and durability. Quality is twofold; production and design that is frequently linked with designers' work. Both must be valued equally for OSM to succeed in architecture. Prefabrication can improve the product precision and thus lead to greater control over the final product. As a result, product warranties are more extensive. Quality and workmanship can be guaranteed by the offsite manufacturer (Smith 2010).

vi) Risk

The parameters were considered very highly (1no.) to highly (3no.). Figure 4.2.5:6 and Table 4.2.5:6 show detailed statistics. This implies the risk parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: quality (unverified fabricators); financial vulnerability to clients, designers and contractors; safety and health (exposure to hazards); and extended producer responsibility (EPR). Risk relates to the exposure to the possibility of incurring losses and hazards at construction sites and other project related risks. Smith (2010) notes that risk to each party is unavoidable during the process of attempting to achieve design and production quality. Prefabrication associated risks include; financial vulnerability to clients, designers and contractors; unverified fabricators; exposure to hazards.

vii) Research and development

All the parameters were considered very highly. Figure 4.2.5:7 and Table 4.2.5:7 show detailed statistics. This implies the research and development parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: contractor design-assist delivery; and cost cutting strategies. Smith (2010) notes that the concept of research and development is linked to quality and risk. OSM allows for early engagement between both the design and construction teams in research and development parameters of design-assist delivery and cost cutting strategies, amongst other considerations.

viii) Sustainability; environmental dimension

The parameters were considered very highly (2no.) to highly (1no.). Figure 4.2.5:8 and Table 4.2.5:8 show detailed statistics. This implies the sustainability (environmental dimension) parameters are important in the decision-making consideration to use OSM concrete building elements. The parameters are: use of sustainable local materials; preventing hazardous and polluting materials; and site disturbance. Smith (2010) notes that architects are the main actors in deciding the material composition of buildings and hence take the lead role in specifying less hazardous and polluting materials.

Offsite manufacturing techniques limit site disturbance and keep affected areas to within the space adjacent to the building footprint as the construction process can be carefully planned to mitigate site disturbances. Acioly *et al.* (2012) outlines the use of sustainable local materials; the prevention of hazardous and polluting materials and the improvement of resilience and adaptation of built forms amongst others as sustainability (environmental dimension) considerations.

ix) Sustainability; social dimension

The parameters were considered very highly (1no.) to highly (2no.). Figure 4.2.5:9 and Table 4.2.5:9 show detailed statistics. This implies the sustainability (social dimension) parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: awareness & public participation; health, safety & wellbeing in the built forms; and jobs created with prefabrication. Acioly *et al.* (2012) outlines ensuring health, safety, wellbeing in the built forms; and empowering people and ensuring public participation amongst others as sustainability (social dimension) considerations.

x) Sustainability; cultural dimension

All the parameters were considered highly. Figure 4.2.5:10 and Table 4.2.5:10 show detailed statistics. This implies the sustainability (cultural dimension) parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: aesthetics (culturally responsive built forms); and promotion of local materials & building techniques. Acioly *et al.* (2012) outlines culturally responsive built forms in planning and design and improving aesthetics amongst others as sustainability (cultural dimension) considerations.

xi) Sustainability; economic dimension

All the parameters were considered very highly. Figure 4.2.5:11 and Table 4.2.5:11 show detailed statistics. This implies the sustainability (economic dimension) parameters are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: affordability on construction costs; and post-occupancy operations. Acioly *et al.* (2012) outlines ensuring affordability for different social groups amongst others as a sustainability (economic dimension) consideration. Smith (2010) notes that Over 90 percent of a building's total lifecycle energy is contributed by operational energy or energy used after occupancy. As a result, some may dismiss the importance of initial energy, believing that project teams should concentrate solely on operational energy that results in a high-performing building at the expense of embodied energy.

xii) Other parameters

The parameters were considered very highly (5no.) to highly (9no.): Figure 4.2.5:12 and Table 4.2.5:12 show detailed statistics. This implies the other parameters discussed are significant in the decision-making consideration to use OSM concrete building elements. The parameters are: design implications; dimensional coordination & module size, design redundancy etc.; transportation, craneage and installation; research and development advancements; retrained and reskilled labour force; optimising and organising onsite work; current and less capital intensive OSM techniques; interface management; interface between each element and between the teams; procurement strategy; building code and statutory approvals; retraining and reskilling; government policy, incentives and promotion; pre-installation trial assemblies or prototypes; IT advances and effect on offsite manufacturing; CAD, BIM; and taxation subsidies on materials.

In order to optimise OSM, Gibb (1999) notes that at an early stage in a project, a project-wide strategy has to be agreed to and implemented, which will necessitate getting relevant information from fabricators. The parameters as listed are discussed in detail under item 2.2.10.

4.3.5 Strategies to Increase the Use of OSM Concrete Building Elements

All the parameters (strategies) were considered very highly. Figure 4.2.6:1 and Table 4.2.6:1 show detailed statistics. This implies the strategies established to increase the use of OSM concrete building elements in building construction projects in Nairobi are highly to very highly appropriate. The strategies are (in the order of higher mean to lower): reviewing building code and statutory approvals; dissemination of current and less capital intensive OSM techniques at national and county levels; research and development advancements; retraining and reskilling of labour force; taxation subsidies on materials; reviewing government policy, incentives and promotion; creating awareness to the public; incorporating content in curriculum of higher learning institutions; and executing some government projects using the techniques. Blismas (2007) and Gbadebo (2014) discuss some of these strategies listed.

These strategies counter the parameters that influence negatively the decision-making to not use offsite manufacturing of concrete building elements in building construction projects in Nairobi. Most of the strategies are government led action, but all the stakeholders in the built environment can influence the execution of the strategies. Of course, offsite manufacturing is not a catch-all solution and thus has to be used with regards to a particular time and place in a construction project.

4.3.6 Hypothesis Review

The study had proposed directional hypotheses aimed at increasing the understanding of the parameters that influence positively and negatively the decision-making to use OSM concrete building elements in building construction projects in Nairobi. Below is a review of the same based on the data collected from the study and discussion done:

Hypothesis 1: Schedule/time and quality, predictability and reliability influence positively the decision-making to utilise OSM concrete building elements. Decision: Accept. All the schedule/time and quality, predictability parameters are highly to very highly considered as positive influences.

Hypothesis 2: Cost, labour & productivity, scope and risk influence negatively the decision-making to not use OSM concrete building elements. Decision: Reject. The parameters of these variables have mixed influences of both positive and negative and can be reviewed at parameter level instead of variable level.

Hypothesis 3: Taxation subsidies on materials and retraining & reskilling of labour force strategies can increase the adoption of offsite manufacturing of concrete building elements when implemented. Decision: Accept. These two parameters are very highly considered as appropriate strategies.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of findings, conclusions and recommendations. The discussion is structured as per the study objectives, which were to identify the types of OSM concrete building elements used in building construction projects in Nairobi; identify the parameters that influence positively and negatively the use of these OSM concrete building elements; establishing parameters that need to be considered in the decision-making to use OSM concrete building elements; and establishing the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

5.2 Summary of Findings

With reference to the first objective, data collected from the survey reveal that only the non-volumetric type of offsite manufacturing of concrete building elements is used in building construction projects in Nairobi. These OSM concrete building elements used include (in the order of most used to least): precast slabs; precast wall panels (load/non-load bearing); other precast concrete elements/products (window sills, wall copings, concrete balusters/railings, paving slabs/blocks); precast beams; precast concrete façade panels/claddings; precast columns; precast staircases; precast concrete girders; precast foundation footings; precast glass fiber reinforced concrete façade panels/cladding; precast concrete roofs; and precast foundation piles.

With reference to the second and third objectives, a comparison was done between the positive influence parameters means against the negative influence parameters means, as shown in detail in Appendix 02. Then depending on the means scoring, an assessment made by the author to which category the parameter has more weight on, either positive or negative influence, or neutral if the difference in the means is 0.1 or less. It can then be interpretated that some variables/parameters have more influence positively than negatively and vice-versa and neutral for some.

With reference to the statement above, the variables/parameters that influence positively the decision-making to use OSM concrete building elements are: i) cost (material, labour, and time costs; and lifecycle costs); ii) schedule/time (delivery duration; installation duration - sequencing & overlap); iii) labour and productivity (skilled; and mindset/perception of productivity efficiency); iv) scope (integration of design team & construction team; and supply chain management); v) quality, predictability and reliability (workmanship; achieving specifications issued, by production & products quality and design quality; and durability); vi) risk (safety and health - exposure to hazards); vii) research and development (contractor design-assist delivery; cost cutting strategies); viii) sustainability - environmental dimension (use of sustainable local materials; preventing hazardous and polluting materials; site disturbance); ix) sustainability - social dimension (health, safety & wellbeing in the built forms; and jobs created with prefabrication); x) sustainability - cultural dimension (aesthetics - culturally responsive built forms; and promotion of local materials & building techniques); and xi) sustainability - economic dimension (affordability on construction costs; and post-occupancy operations).

The variables/parameters that influence negatively the decision-making to not use OSM concrete building elements are: i) cost (initial capital costs - fabrication facility costs; upfront design fees costs; and transportation costs and craneage); ii) risk (financial vulnerability to clients, designers and contractors); iii) sustainability - social dimension (awareness & public participation); and iv) other parameters (influence/not from government projects executed using the OSM techniques; research and development advancements/lack; retrained and reskilled labour force/lack; favorable/lack government policy, incentives and promotion; favorable/lack building code and statutory approvals; current and less capital intensive OSM techniques disseminated/lack; mindsets and perceptions).

The variables/parameters that were considered neutral from the data collected on the decision-making to use OSM concrete building elements are: i) labour and productivity (prefabrication technology technical knowhow/knowledge; and training); ii) scope (complexity/extent of project); iii) risk (quality - unverified fabricators; and extended producer responsibility); and iv) other parameters (awareness/lack of the OSM techniques). This variance in response of considering these 6no. parameters as highly influencing both positively and negatively the use of OSM concrete building elements can be interpreted as responses based on the personal experiences of the respondents in their decision-making to use OSM concrete building elements and not generalized as neutral factors.

With reference to the fourth objective, all the parameters of cost; schedule/time; labour and productivity; scope; quality, predictability and reliability; risk; research and development; sustainability (environmental dimension, social dimension, cultural dimension, economic dimension); and other parameters need to be considered highly to very by the respondents highly in the decision-making to use OSM concrete building elements. The other parameters are: design implications; dimensional coordination & module size, design redundancy etc.; transportation, craneage and installation; research and development advancements; retrained and reskilled labour force; optimising and organising onsite work; current and less capital intensive OSM techniques; interface management; interface between each element and between the teams; procurement strategy; building code and statutory approvals; retraining and reskilling; government policy, incentives and promotion; pre-installation trial assemblies or prototypes; IT advances and effect on offsite manufacturing; CAD, BIM; and taxation subsidies on materials.

With reference to the fifth objective, all the strategies established that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi were considered very highly by the respondents. Listed in the order of higher mean to lower, the strategies established are: reviewing building code and statutory approvals; dissemination of current and less capital intensive OSM techniques at national and county levels; research and development advancements; retraining and reskilling of labour force; taxation subsidies on materials; reviewing government policy, incentives and promotion; creating awareness to the public; incorporating content in curriculum of higher learning institutions; and executing some government projects using the techniques.

5.3 Conclusion

From the findings of the survey, only the non-volumetric type of OSM concrete building elements is used. 39% of the respondents not having used the OSM concrete building elements. The two statistics depict low usage of the OSM concrete building elements. It can be concluded that appropriate strategies need to be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi. This study has established some of the appropriate strategies.

The study further assessing the operationalisation of offsite manufacturing of concrete building elements in building construction projects in Nairobi through the objectives and questions set, adopted 41no. parameters from 8no. variables: cost; schedule/time; labour and productivity; scope; quality, predictability and reliability; risk; research and development; and sustainability (environmental dimension, social dimension, cultural dimension, economic dimension). The results from the survey have been discussed under item 4.3 and summarized under item 5.2.

Of the 41no. parameters adopted for the study; 23no. parameters were considered to have influenced positively; 12no. parameters were considered to have influenced negatively; and 6no. parameters were considered by the respondents as highly influencing both positively and negatively the use of OSM concrete building elements with minimal margins in their means. These 6no. parameters were considered neutral by the author's review as explained under item 5.2. These are: i) labour and productivity (prefabrication technology technical knowhow/knowledge; and training); ii) scope (complexity/extent of project); iii) risk (quality - unverified fabricators; and extended producer responsibility); and iv) other parameters (awareness/lack of the OSM techniques). Responses need to be collected from a much wider sample size, probably at a national level, to help swing the means and differences on either positively influencing parameters or negatively influencing parameters.

Significant to note was the high to very high consideration given to the 41no. parameters used in the survey as parameters that need to be considered in the decision-making to use OSM concrete building elements. Similarly, all the strategies proposed during the study that if implemented could increase the adoption of OSM concrete building elements in building construction projects in Nairobi, were considered very highly.

5.4 Limitation of Findings

The study assessed 41no. parameters to achieve the study objectives and questions in assessing the operationalisation of offsite manufacturing of concrete building elements in building construction projects in Nairobi. As part of the data presentation and analysis, several relationships between the findings of the data collected were discussed. The author intended to investigate more relationships than the ones discussed. This was to be achieved with the multivariate regression analysis, using the SPSS tool, to establish the correlation between several independent variables and the one dependent variable. The multivariate regression analysis would have been appropriate for the investigation of such relationships. The main challenge to this was the magnitude of data that was being generated out of this analysis to which the time constraints limited the analysis of the same. This was so because there were 31no. parameters to be analysed; 21no. parameters adopted from the 6no. independent variables (cost; schedule/time; labour and productivity; scope; quality, predictability; and reliability; risk) and the 10no. parameters adopted from the 1no. dependent variable (sustainability; environmental dimension, social dimension, cultural dimension, and economic dimension).

5.5 Contribution to Knowledge

Based on the data collected from the survey, the usage of offsite manufacturing of concrete building elements has not progressed as much in building construction projects in Nairobi. The study has identified the types and extent of OSM concrete building elements usage in building construction projects in Nairobi; identified the parameters that influence positively and negatively the use of these OSM concrete building elements; established parameters that need to be considered in the decision-making to use OSM concrete building elements; and established the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

As noted in the problem statement, embracing offsite manufacturing, in this case of concrete building elements, can turn the housing shortage in Nairobi into a manageable task and help increase the housing supply within much shorter timeframes. The data collected and analysed in this report, from the primary and secondary data sources, can be resourceful to the various built environment stakeholders in their decision-making to use offsite manufacturing of concrete building elements in building construction projects in Nairobi.

5.6 Recommendations

The findings depict low usage of the OSM concrete building elements in building construction projects in Nairobi. The recommendations from this study are guided by the findings of low usage of the OSM concrete building elements together with the fourth and fifth objectives, which were to establish parameters that need to be considered in the decision-making to use OSM concrete building elements; and to establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

All the parameters need to be considered in the decision-making to use OSM concrete building elements in building construction projects in Nairobi. The parameters of cost; schedule/time; labour and productivity; scope; quality, predictability and reliability; risk; research and development; sustainability (environmental dimension, social dimension, cultural dimension, economic dimension); and other parameters need to be considered highly to very by the respondents highly in the decision-making to use OSM concrete building elements. The other parameters are: design implications; dimensional coordination & module size, design redundancy etc.; transportation, craneage and installation; research and development advancements; retrained and reskilled labour force; optimising and organising onsite work; current and less capital intensive OSM techniques; interface management; interface between each element and between the teams; procurement strategy; building code and statutory approvals; retraining and reskilling; government policy, incentives and promotion; pre-installation trial assemblies or prototypes; IT advances and effect on offsite manufacturing; CAD, BIM; and taxation subsidies on materials.

The appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi are: taxation subsidies on materials; creating awareness to the public; incorporating content in curriculum of higher learning institutions; executing some government projects using the techniques; research and development advancements; retraining and reskilling of labour force; reviewing government policy, incentives and promotion; reviewing building code and statutory approvals; and dissemination of current and less capital intensive OSM techniques.

5.7 Areas of Further Research

This study highlighted matters of site safety and health at some of the offsite manufacturing/fabrication facilities were not taken with utmost seriousness they require. Future studies can be conducted to assess how the incompliance of standard health and safety regulations at these offsite manufacturing facilities affects productivity, quality amongst others.

Having highlighted and acknowledged the significance of offsite manufacturing in comparison to onsite construction, future studies can be conducted on different building elements other than concrete building elements.

As also highlighted in the limitations of the study, time and financial constraints limited the extent of this study to Nairobi. Future studies can be conducted at a national level scope. This can help detail the extent of the operationalisation of offsite manufacturing of concrete building elements in building construction projects in Kenya.

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APPENDICES

APPENDIX 01: A Multi-Scale Framework for Policies on Sustainable Housing. Source: Acioly *et al.* (2012).

	Macro (National)	Meso (Region, City)	Micro (Neighborhood, Household)
Environmental dimension	Housing to support climate mitigation and adaptation efforts. Mainstreaming green housing practices and innovations. Ensuring energy and resource efficiency in the building industry. Integrating national housing and energy systems.	Achieving good location and density for residential areas and access to infrastructure. Serviced land in environmentally safe locations and green areas. Protection of ecosystems and biodiversity. Promoting sustainable and low-carbon urban infrastructure, public transport and non-motorised mobility, energy systems. Waste management and recycling.	Ensuring energy efficiency, microgeneration, water and resource efficiency. Green design, using sustainable local construction and materials. Sanitation, preventing hazardous and polluting materials. Affordable use of resources. Improving resilience and adaptation of homes.
Social dimension	Fulfilling the right to adequate housing and promoting the right to the city. Ensuring affordable, decent and suitable homes for all, including disadvantaged groups. Developing social housing provision. Promoting choice and security of tenure.	Promoting integrated communities and ensuring trust in communities. Providing community facilities, preventing segregation and displacement. Regenerating and reintegrating 'neglected' areas into regional, urban fabric. Ensuring infrastructural integration of housing into wider areas. Upgrading inadequate housing and slum areas.	Empowering people and ensuring public participation. Ensuring health, safety, well-being in residences. Creating a sense of community, 'sense of place' and identity. Meeting specific needs and wants in housing (including those related to gender, age and health). Providing access to infrastructure and public spaces.
Cultural dimension	Promoting links between housing and knowledge-based and cultural economies. Promoting traditional, indigenous and local knowledge (including of relevance to	Promoting urban creativity, culture, aesthetics, diversity. Shaping values, tradition, norms and behaviours (e.g. in relation to energy use, recycling, communal	Culturally responsive settlements and house planning and design. Improving aesthetics, diversity and cultural sophistication of the built environment and residence.

	sustainable resource use, energy efficiency and resilient building techniques). Protecting cultural heritage.	living and place maintenance). Protecting housing heritage and familiarity of city (e.g. preventing unnecessary social replacement/ gentrification or complete redevelopment.	Helping community creativity (i.e. via amenities; affordable sporting, cultural and entertainment facilities. Assisting people's transition from rural and slums areas to decent housing or multifamily housing.
Economic dimension	Institutional capacities for sustainable housing markets and housing development. Articulating housing productivity within national economic systems. Improving housing supply and effective demand, stabilising housing markets. Improving housing finance options. Promoting innovations in housing. Stimulating necessary technological developments for sustainable housing.	Managing economic activities and growth by strengthening housing provision and housing markets. Provision of necessary infrastructure and basic services to housing. Providing serviced land for housing. Strengthening entrepreneurship of communities, local building industry and enterprise. Promoting local and traditional building materials and techniques. Promoting regional and urban regeneration.	Ensuring housing affordability for different social groups. Providing adequate residences to raise labour productivity; ensuring housing is integrated with employment. Supporting domestic economic activities and enterprise. Promoting petty landlordism and self-help housing. Housing management and maintenance. Strengthening resilience and future proofing of homes.

APPENDIX 02: Comparison Between the Positive Influence Parameters Means Against Negative Influence Parameters Means.

Source: Field survey (2021).

Variable	**What was Assessed**	**Positive Influence Mean**	**Negative Influence Mean**	**Remarks: +ve, -ve or Neutral?**
Cost	Initial capital costs; fabrication facility costs	3.085	3.935	Negative
	Upfront design fees costs	2.532	2.774	Negative
	Material, labour, and time costs	3.766	3.226	Positive
	Transportation costs and craneage	3.043	4.065	Negative
	Lifecycle costs	3.170	2.258	Positive
Schedule/Time	Delivery duration	4.104	2.935	Positive
	Installation duration; sequencing & overlap	4.333	2.677	Positive
Labour and Productivity	Skilled/unskilled	3.688	3.226	Positive
	Prefabrication technology technical know-how/knowledge	3.854	3.774	Neutral
	Training	3.479	3.452	Neutral
	Mindset/perception of productivity efficiency	3.563	3.161	Positive
Scope	Complexity/extent of project	3.521	3.613	Neutral
	Integration of design team & construction team	3.438	3.323	Positive
	Supply chain management	3.319	2.839	Positive
Quality, Predictability and Reliability	Workmanship	4.292	3.161	Positive
	Achieving specifications issued, by production & products quality and design quality	4.167	3.129	Positive
	Durability	3.723	2.419	Positive
Risk	Quality; unverified fabricators	3.521	3.452	Neutral
	Financial vulnerability to clients, designers and contractors	3.292	3.613	Negative
	Safety and health; exposure to hazards	3.583	2.516	Positive

	Extended producer responsibility	3.191	3.290	Neutral
Research and Development	Contractor design-assist delivery	3.563	3.032	Positive
	Cost cutting strategies	4.063	3.194	Positive
Sustainability				
Environmental Dimension	Use of sustainable local materials	3.458	2.903	Positive
	Preventing hazardous and polluting materials	3.340	2.645	Positive
	Site disturbance	3.813	2.710	Positive
Social Dimension	Awareness & public participation	2.723	2.968	Negative
	Health, safety & wellbeing in the built forms	3.553	2.839	Positive
	Jobs created with prefabrication	3.085	2.323	Positive
Cultural Dimension	Aesthetics; culturally responsive built forms	3.583	2.613	Positive
	Promotion of local materials & building techniques	3.333	2.516	Positive
Economic Dimension	Affordability on construction costs	4.000	3.774	Positive
	Post-occupancy operations	3.468	2.806	Positive
Other Parameters				
Awareness/lack of the OSM techniques		3.521	3.419	Neutral
Influence/not from government projects executed using the OSM techniques		2.271	2.613	Negative
Research and development advancements/lack		3.188	3.323	Negative
Retrained and reskilled labour force/lack		3.208	3.484	Negative
Favorable/lack government policy, incentives and promotion		2.375	3.032	Negative
Favorable/lack building code and statutory approvals		2.667	3.323	Negative
Current and less capital intensive OSM techniques disseminated/lack		3.104	3.516	Negative
Mindsets and perceptions		No data	3.484	Negative

APPENDIX 03: Author's Data Collection Introduction Note

Hello,

I am Charles Ghati, an MA Construction Management student at the University of Nairobi, currently undertaking my research project titled *'Operationalisation of Offsite Manufacturing of Concrete Building Elements in Building Construction Projects in Nairobi*'.

This questionnaire aims to collect information on: the types of offsite manufacturing (OSM) of concrete building elements used in building construction projects in Nairobi; identify the parameters that influence positively and negatively the use of these OSM concrete building elements; establish parameters that need to be considered in the decision-making to use OSM concrete building elements; and establish the appropriate strategies that can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi.

This questionnaire is meant to help collect data for the research. The data collected will only be used for the purposes of the research and will be anonymous. I am targeting the built environment stakeholders and would be very grateful if you participated. Kindly take a few minutes to respond. Click here to access the questionnaire.

Thank you!

Charles Ghati

APPENDIX 04: UoN Research Letter of Introduction

UNIVERSITY OF NAIROBI

DEPARTMENT OF REAL ESTATE & CONSTRUCTION MANAGEMENT & QUANTITY SURVEYING

P.O. Box 30197, 00100 Nairobi, KENYA, ***Tel: No. 020-491 3531/2***

E-mail: *dept-cmqs@uonbi.ac.ke*

Ref: B53/11189/2018 **Date:** 13th September, 2021

To Whom It May Concern

Dear Sir/Madam,

<u>RE: RESEARCH LETTER – CHARLES MWITA GHATI</u>

This is to confirm that the above named is a student in the Department of Real Estate, Construction Management & Quantity Surveying pursuing a course leading to the degree of M.A. Construction Management.

He is carrying out a research *entitled* ***"Operationalisation of Offsite Concrete Works Manufacturing Techniques in Building Construction Projects in Nairobi"*** in partial fulfillment of the requirements for the degree programme.

The purpose of this letter is to request you to allow him access to any kind of material he may require to complete his research. The information will be used for research purposes only.

CHAIRMAN
DEPARTMENT OF CONSTRUCTION
MANAGEMENT AND QUANTITY SURVEYING
UNIVERSITY OF NAIROBI

<u>Isabella N. Wachira-Towey, (PhD)</u>
Chair & Senior Lecturer,
Department of Real Estate, Construction Management & Quantity Surveying.

APPENDIX 05: Questionnaire

Administered through google forms (link).

Section A: Respondent Information (Tick as appropriate)

1. What is your role in the built environment?
   a) Consultant; Project Manager [ ] Architect [ ] Structural Engineer [ ] Quantity Surveyor [ ]
   b) Developer [ ]
   c) Contractor [ ]
   d) Manufacturer [ ]
   e) Other; please specify ________________________
2. What is the categorisation of your organisation?
   a) Private [ ]
   b) Government [ ]
   c) NGO [ ]
3. What is your professional experience in the built environment?
   1 – 3 years [ ] 4 – 5 years [ ] 6 – 10 years [ ] Above 10 years [ ]

Section B: Operationalisation of Offsite Manufacturing

4. Have you used offsite manufacturing of concrete building elements in your building construction projects in Nairobi?
   Yes [ ] No [ ]
5. If 'Yes' to no. 4, what offsite manufacturing of concrete building elements have you used in your building construction projects in Nairobi?
   Non-volumetric [ ] Volumetric [ ] Modular [ ]
   *Non-volumetric; singular building components not enclosing space such as parts of the structural frame or cladding of a building, concrete internal partitions, staircases, concrete parts of building services etc. **Volumetric; enclosed usable space not constituting the whole building such as plant rooms, toilets etc. ***Modular; units that form a complete building or part of a building, including the structure and envelope. *~Multiple responses can be selected.*
6. Check the OSM concrete building elements/products you have used in your building construction projects in Nairobi

OSM concrete building elements/products	√
Precast foundation footings	
Precast foundation piles	
Precast slabs	
Precast columns	
Precast beams	
Precast concrete girders	
Precast wall panels; load bearing/non-load bearing	
Precast concrete roofs	
Precast concrete façade panels/claddings	
Precast glass fiber reinforced concrete façade panels/claddings	
Precast staircases	
Other precast concrete elements/products; window sills, wall copings, concrete balusters/railings, paving slabs/blocks	
Other: please specify	

7. How did the parameters in this section influence your decision positively to use offsite manufacturing of concrete building elements in your building construction projects in Nairobi? Using a 5-point likert scale, score their consideration level, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high consideration, 5 = very high consideration. Tick (√) as appropriate. A response is required in each row.

Cost	**1**	**2**	**3**	**4**	**5**
Initial capital costs; fabrication facility costs					
Upfront design fees costs					
Material, labour, and time costs					
Transportation costs and craneage					
Lifecycle costs					

Schedule/Time	**1**	**2**	**3**	**4**	**5**
Delivery duration					

Installation duration; sequencing & overlap					

Labour and Productivity	**1**	**2**	**3**	**4**	**5**
Skilled					
Prefabrication technology technical know-how/knowledge					
Training					
Mindset/perception of productivity efficiency					

Scope	**1**	**2**	**3**	**4**	**5**
Complexity/extent of project					
Integration of design team & construction team					
Supply chain management					

Quality, Predictability and Reliability	**1**	**2**	**3**	**4**	**5**
Workmanship					
Achieving specifications issued, by production & products quality and design quality					
Durability					

Risk	**1**	**2**	**3**	**4**	**5**
Quality; unverified fabricators					
Financial vulnerability to clients, designers and contractors					
Safety and health; exposure to hazards					
Extended producer responsibility					

Research and Development	**1**	**2**	**3**	**4**	**5**
Contractor design-assist delivery					
Cost cutting strategies					

Sustainability; Environmental Dimension	**1**	**2**	**3**	**4**	**5**
Use of sustainable local materials					

Preventing hazardous and polluting materials					
Site disturbance					

Sustainability; Social Dimension	**1**	**2**	**3**	**4**	**5**
Awareness & public participation					
Health, safety & wellbeing in the built forms					
Jobs created with prefabrication					

Sustainability; Cultural Dimension	**1**	**2**	**3**	**4**	**5**
Aesthetics; culturally responsive built forms					
Promotion of local materials & building techniques					

Sustainability; Economic Dimension	**1**	**2**	**3**	**4**	**5**
Affordability on construction costs					
Post-occupancy operations					

Other Parameters that Influenced Positively	**1**	**2**	**3**	**4**	**5**
Awareness of the OSM techniques					
Influence from government projects executed using the OSM techniques					
Research and development advancements					
Retrained and reskilled labour force					
Favorable government policy, incentives and promotion					
Favorable building code and statutory approvals					
Current and less capital intensive OSM techniques disseminated					
Others; list					

8. In your opinion, what other parameters influenced your decision positively to use offsite manufacturing of concrete building elements in your building construction projects in Nairobi? ____
____
____
____

9. If you answered 'No' to no. 4, did you consider to use offsite manufacturing of concrete building elements in your building construction projects in Nairobi?
Yes [ ]   No [ ]

10. How did the parameters in this section inform your decision to not use offsite manufacturing of concrete building elements in your building construction projects in Nairobi? Using a 5-point likert scale, score their consideration level, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high consideration, 5 = very high consideration. Tick (√) as appropriate. A response is required in each row.

Cost	**1**	**2**	**3**	**4**	**5**
Initial capital costs; fabrication facility costs					
Upfront design fees costs					
Material, labour, and time costs					
Transportation costs and craneage					
Lifecycle costs					

Schedule/Time	**1**	**2**	**3**	**4**	**5**
Delivery duration					
Installation duration; sequencing & overlap					

Labour and Productivity	**1**	**2**	**3**	**4**	**5**
Unskilled					
Prefabrication technology technical know-how/knowledge					
Training					
Mindset/perception of productivity efficiency					

Scope	**1**	**2**	**3**	**4**	**5**
Complexity/extent of project					
Integration of design team & construction team					
Supply chain management					

Quality, Predictability and Reliability	**1**	**2**	**3**	**4**	**5**
Workmanship					
Achieving specifications issued, by production & products quality and design quality					
Durability					

Risk	**1**	**2**	**3**	**4**	**5**
Quality; unverified fabricators					
Financial vulnerability to clients, designers and contractors					
Safety and health; exposure to hazards					
Extended producer responsibility					

Research and Development	**1**	**2**	**3**	**4**	**5**
Contractor design-assist delivery					
Cost cutting strategies					

Sustainability; Environmental Dimension	**1**	**2**	**3**	**4**	**5**
Use of sustainable local materials					
Preventing hazardous and polluting materials					
Site disturbance					

Sustainability; Social Dimension	**1**	**2**	**3**	**4**	**5**
Awareness & public participation					
Health, safety & wellbeing in the built forms					
Jobs created with prefabrication					

Sustainability; Cultural Dimension	**1**	**2**	**3**	**4**	**5**
Aesthetics; culturally responsive built forms					
Promotion of local materials & building techniques					

Sustainability; Economic Dimension	**1**	**2**	**3**	**4**	**5**
Affordability on construction costs					
Post-occupancy operations					

Other Parameters that Influenced Negatively	**1**	**2**	**3**	**4**	**5**
Lack of awareness created					
Mindsets and perceptions					
Government projects not being executed using the OSM techniques					
Lack of research and development advancements					
Lack of retraining and reskilling labour force					
Lack of favorable government policy, incentives and promotion					
Lack of favorable building code and statutory approvals					
Lack of dissemination of current and less capital intensive OSM techniques					
Others; list					

11. In your opinion, what other parameters informed your decision negatively to not use offsite manufacturing of concrete building elements in your building construction projects in Nairobi? ____

____

____

____

12. What parameters need to be considered in the decision-making to use offsite manufacturing of concrete building elements in building construction projects in Nairobi? Using a 5-point likert scale, score their consideration level, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high consideration, 5 = very high consideration. Tick (√) as appropriate. A response is required in each row.

Cost	**1**	**2**	**3**	**4**	**5**
Initial capital costs; fabrication facility costs					
Upfront design fees costs					
Material, labour, and time costs					
Transportation costs and craneage					
Lifecycle costs					

Schedule/Time	**1**	**2**	**3**	**4**	**5**
Delivery duration					
Installation duration; sequencing & overlap					

Labour and Productivity	**1**	**2**	**3**	**4**	**5**
Skilled/unskilled					
Prefabrication technology technical know-how/knowledge					
Training					
Mindset/perception of productivity efficiency					

Scope	**1**	**2**	**3**	**4**	**5**
Complexity/extent of project					
Integration of design team & construction team					
Supply chain management					

Quality, Predictability and Reliability	**1**	**2**	**3**	**4**	**5**
Workmanship					
Achieving specifications issued, by production & products quality and design quality					

Durability					

Risk	**1**	**2**	**3**	**4**	**5**
Quality; unverified fabricators					
Financial vulnerability to clients, designers and contractors					
Safety and health; exposure to hazards					
Extended producer responsibility					

Research and Development	**1**	**2**	**3**	**4**	**5**
Contractor design-assist delivery					
Cost cutting strategies					

Sustainability; Environmental Dimension	**1**	**2**	**3**	**4**	**5**
Use of sustainable local materials					
Preventing hazardous and polluting materials					
Site disturbance					

Sustainability; Social Dimension	**1**	**2**	**3**	**4**	**5**
Awareness & public participation					
Health, safety & wellbeing in the built forms					
Jobs created with prefabrication					

Sustainability; Cultural Dimension	**1**	**2**	**3**	**4**	**5**
Aesthetics; culturally responsive built forms					
Promotion of local materials & building techniques					

Sustainability; Economic Dimension	**1**	**2**	**3**	**4**	**5**
Affordability on construction costs					
Post-occupancy operations					

Other Parameters to be Considered	**1**	**2**	**3**	**4**	**5**
Procurement strategy					
Interface management; interface between each element and between the teams					
Design implications; dimensional coordination & module size, design redundancy etc.					
IT advances and effect on offsite manufacturing; CAD, BIM					
Pre-installation trial assemblies or prototypes					
Transportation, craneage and installation					
Optimising and organising onsite work					
Retraining and reskilling					
Taxation subsidies on materials					
Research and development advancements					
Retrained and reskilled labour force					
Government policy, incentives and promotion					
Building code and statutory approvals					
Current and less capital intensive OSM techniques					
Others; list					

13. In your opinion, what other parameters need to be considered in the decision-making to use offsite manufacturing of concrete building elements in building construction projects in Nairobi? ____

____

____

____

14. What appropriate strategies can be implemented to increase the use of offsite manufacturing of concrete building elements in building construction projects in Nairobi? Using a 5-point likert scale, score their consideration level, where; 1 = lowest consideration, 2 = slight consideration, 3 = moderate consideration, 4 = high

consideration, 5 = very high consideration. Tick (√) as appropriate. A response is required in each row.

Strategies to be Considered	**1**	**2**	**3**	**4**	**5**
Taxation subsidies on materials					
Creating awareness to the public					
Incorporating content in curriculum of higher learning institutions					
Executing some government projects using the techniques					
Research and development advancements					
Retraining and reskilling of labour force					
Reviewing government policy, incentives and promotion					
Reviewing building code and statutory approvals					
Dissemination of current and less capital intensive OSM techniques					
Others; list					

15. In your opinion, what other appropriate strategies can be implemented to increase the use of offsite manufacturing of concrete building elements in building construction projects in Nairobi? ____

____

____

____

16. Any comments/thoughts on the use of offsite manufacturing of concrete building elements in building construction projects in Nairobi? ______________________

____

____

____

17. Name & email/phone number? (Optional)_________________________________

~Thank you for participating in this study!~

APPENDIX 06: Interview Schedule

Targeted interviewees are project managers, architects, structural engineers, quantity surveyors, developers, contractors, manufacturers and other stakeholders in the built environment not listed. The interviews are meant to complement the response rate from questionnaires, in the case where the response rate is low. Alongside the in-person administration of questionnaires to the interviewees, the research questions will also be asked to capture their broader familiarity.

Questions	**Date & Duration**
Which OSM concrete building elements are used in building construction projects in Nairobi?	October 2021 1 hour to 2 hours per respondent
What parameters influence positively the decision to use OSM concrete building elements in Nairobi?	
What parameters influence negatively the decision to not use OSM concrete building elements in Nairobi?	
What parameters need to be considered in the decision to use OSM concrete building elements in Nairobi?	
What appropriate strategies can be implemented to increase the adoption of OSM concrete building elements in building construction projects in Nairobi?	

APPENDIX 07: Observation Checklist

Visiting sites will form part of the data collection by observing how contractors are integrating offsite and onsite manufacturing.

Item	**Remarks**
Optimising/organising onsite work to accommodate the offsite manufacturing	
Quality	
Interface management	
Pre-installation trial assemblies or prototypes	
Risk parameters	
Transportation, craneage	
Labour, skilled?	
Technical know-how/knowledge	
Information technology; BIM	
Sustainability parameters	