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# Investigating Productivity of Modular Buildings

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INVESTIGATING PRODUCTIVITY OF MODULAR BUILDINGS

By

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# Abstract

The modular construction industry has grown substantially, yet understanding of the relationships between project categories, sizes, and productivity remains limited. This study investigates these relationships in both permanent and relocatable modular construction projects across different sectors, including multifamily housing, dormitories, healthcare, education, retail, office, and workforce housing. Data from 303 permanent and 188 relocatable projects in the Modular Building Institute database were analyzed using Kendall's tau-b correlation and linear regression analyses. Key findings reveal that permanent projects outnumber and are generally larger than relocatable ones, with education being the most common project type. Significant positive correlations between project size and productivity were found in most categories, with workforce housing showing the highest productivity rates. Productivity varied widely, ranging from 50 to 165.7 square feet per day. The correlation was stronger in permanent structures compared to relocatable ones, with significant positive correlations observed in all permanent categories except hotels, and in all relocatable categories except healthcare and retail.

This study contributes to the body of knowledge by providing empirical evidence of productivity trends across different modular construction types and sizes. For practice, it offers tools for productivity forecasting and project selection, highlighting the potential benefits of larger modular projects. These insights can guide strategic decision-making in project portfolio management, potentially leading to improved overall productivity and efficiency in modular construction operations.

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# Chapter 1: Introduction

## 1.1 Background

Labor productivity is a cornerstone of economic health, particularly in the United States' construction on industry. It plays a vital role in critical tasks such as budgeting, estimating, and scheduling, offering valuable insights into industry trends and improvements (El-Gohary et al. 2017; Vereen et al. 2016). The significance of the construction sector to the U.S. economy is undeniable, accounting for 5.3% of the GDP in 2011 and employing about 8% of the total workforce (Bureau of Labor Statistics 2006). As such, the productivity of this major sector is crucial for overall economic growth and stability.

Despite its economic importance, the construction sector has been grappling with stagnant labor productivity growth in recent years. In the United States, the productivity of construction workers has decreased by an average of 1.7 percent each year since 1968, while the productivity of the entire economy has increased by 1.6 percent over the same time frame (Sveikauskas et al. 2016). Construction fell even further behind some industries that saw significant productivity increases. For example, agriculture saw its productivity rise by 4.5 percent from 1947 to 2010, while retail experienced a yearly growth of 3.4 percent (McKinsey and Company 2017). This concerning trend has prompted the industry to explore innovative approaches to boost efficiency and productivity.

One such innovative approach is modularization, defined as a project execution strategy that transfers construction efforts from the job site to fabrication shops or yards (Hasan et al. 2024; Kluck and Choi 2023). The proper implementation of this method ensures a considerable opportunity to improve project performance by reducing capital costs, project duration, construction waste, accidents and noise, and can also improve labor productivity (Allmon et al. 2000; Choi and Kim 2019; McGrew-Hill Construction 2011; Modular Building Institute 2010; O'Connor et al. 2013; Song et al. 2005; Tatum et al. 1986).

Modular construction presents numerous advantages over conventional stick-built methods, addressing many of the productivity issues plaguing the industry. It promotes sustainable practices by reducing material usage and waste, enhances productivity, decreases costs and construction time and improves safety by relocating most activities to controlled factory settings (Azhar et al. 2013; Kamali and Hewage 2017; Mah 2011; Paliwal et al. 2021). Additional benefits include reduced weather-related delays, improved quality control, and minimized on-site congestion and hazards. Some other softer benefits of modular construction include reduced risk/ contingency benefits, reduced site footprint benefits, environmental benefits, social benefits and governance benefits (Shahi et al. 2024). These advantages position modular construction as a potential game-changer in addressing the sector's productivity challenges.

The versatility of modular construction extends its applicability across a wide range of contexts, including residential, commercial, and industrial settings (Modular Building Institute 2023a). Within the commercial realm, modular buildings are categorized into two distinct types:

permanent modular construction (PMC) and relocatable modular construction (RMC). Permanent modular buildings are “designed to remain in one location for an extended period of time” (Modular Building Institute 2021). In contrast, RMCs are designed for multiple uses and transportability across different sites, as defined by the International Existing Building Code (Modular Building Institute 2023b). Both PMC and RMC encompass a diverse array of project types, from multifamily housing and dormitories to healthcare facilities, educational institutions, retail outlets, and office complexes. This wide-ranging applicability underscores the potential of modular construction to transform various sectors of the built environment.

While extensive research has been conducted on productivity in traditional stick-built construction, there is a significant knowledge gap regarding productivity specifically in modular construction. This gap is particularly evident in the lack of comprehensive studies examining the relationship between project size and productivity across various categories of modular building projects.

Despite the growing adoption of modular construction techniques, the industry lacks a nuanced understanding of how productivity varies across different project types and sizes. Specifically, there is an absence of research exploring the correlation between the gross size of modular projects and their productivity rates (measured as gross size completed per day) across various categories such as multifamily housing, dormitories, offices, and retail spaces.

The current study aims to address this gap by conducting a pioneering analysis of the relationship between project size and productivity in modular construction. By utilizing both

Kendall's tau-b correlation and linear regression analysis across multiple project categories, this study provides unprecedented insights into the dynamics of productivity in modular construction. This approach represents a novel contribution to the field, as no previous studies have undertaken such a comprehensive, category-specific analysis of productivity in relation to project size in modular construction.

## 1.2 Problem Statement

The construction industry has been grappling with stagnant labor productivity growth, unlike other sectors that have seen significant improvements. While modular construction offers a promising solution to this issue, there is a critical lack of comprehensive understanding regarding how size of modular projects correlates with productivity across different modular building types, such as multifamily housing, dormitories, offices, and retail spaces. By providing insights into these productivity dynamics, findings will help the practitioners to make informed decisions when they consider modular construction over stick-built construction methods by showing the productivity by project type. Also, the results on the relationship between productivity and size in modular buildings will show that larger-size projects can be more productive, which can also convince the practitioners who consider high-rise or big projects.

## 1.3 Research Scope and Objectives

This study aims to investigate the relationship between project size and productivity rates in modular construction across various project categories. The study specifically examines data from the Modular Building Institute database (Modular Building Institute 2024), which includes both permanent and relocatable modular construction projects in different categories, such as multifamily, dormitory, correctional, special application, health, education, retail, office, and workforce housing.

The project data was collected on January $7^{th}$, 2024. Project data, including gross square footage and number of days required for completion, the company name, and the location was collected. Additionally, the gross size of the project and the number of days required for completion was analyzed to calculate productivity rates. Key topics to be explored include modular construction techniques, productivity measurement in construction, and statistical analysis methods such as Kendall's tau-b correlation and linear regression. The geographical scope encompasses projects mainly within the continental United States and Canada; however, projects are still present from different parts of the globe.

The research objectives are:

1. To investigate the correlations between the size of construction projects and their productivity in various categories.

2. To identify productivity patterns among various project categories in the modular building sector.

3. To investigate the characteristics of modular building projects by conducting a descriptive analysis of modular building projects.

- Frequency of Modular Projects
- Size of Modular Projects
- Productivity of Modular Projects

## 1.4 Research Hypothesis

- Primary Research Hypothesis (H1): There is a positive correlation between project size and productivity in modular construction across different categories. Null Hypothesis (H0): There is no significant correlation between project size and productivity in modular construction across different categories.
- Secondary Research Hypothesis (H2): There exists a linear relationship between project size (independent variable) and productivity (dependent variable) in modular construction projects. Null Hypothesis (H0): There is no significant linear relationship between project size and productivity in modular construction projects.

## 1.5 Study Limitations

This study has the following limitations:

- Data Completeness and Consistency: The database exhibits discrepancies or gaps in the reported data, including missing information regarding project details, completion times, or gross project quantities. Moreover, the methodology used to gather and report data may differ among various projects or contributors, which could potentially result in inconsistencies or biases in the dataset.
- Restricted Access to Project-Specific Details: Although the database contains data on project categories, sizes, and completion times, it may not include in-depth information on project-specific factors such as site conditions, resource availability, design complexities, or logistical challenges. These factors have the potential to impact productivity and completion timelines.
- Limitation in Accounting for External Factors: The study's use of the Modular Building Institute database may hinder the ability to consider external factors that could affect modular construction projects, such as economic circumstances, regulatory modifications, disruptions in the supply chain, or technological advancements. These factors have the potential to impact productivity and the time it takes to complete projects.
- Timing of Projects: The database likely includes projects completed over a range of years. Older projects may not reflect current practices, technologies, or efficiencies in modular construction. Additionally, projects from different time periods may have been influenced by varying economic conditions, regulations, or industry standards, which could affect the comparability of data across the dataset.

- Timing of Study: The study's analysis is based on data available at a specific point in time (January 7th, 2024). This snapshot approach may not capture ongoing trends or recent developments in the modular construction industry, potentially limiting the applicability of findings to current or future projects.

## 1.6 Thesis Structure

The research is structured into six chapters. The first chapter provides an overview of the study's background and highlights the necessity of conducting the investigation. The chapter also addresses the research gap and outlines the study's aims. The chapter also addresses the scope and limitations of the investigation. Chapter two focuses on the literature review and provides a concise summary of the literature's results and identifies the gap in the body of literature. The chapter centers on the literature pertaining to the factors affecting traditional and modular building productivity, the current state of construction productivity, permanent modular construction, relocatable modular construction, and the measurement and analysis of construction productivity. Chapter 3 of the study focuses on the research flowchart which includes problem identification and literature review, data identification and data source identification, calculation of modular construction productivity, and data analysis. Chapter 4 examines the study's findings and delves into the frequency analysis of the project categories, the primary analytical measure of the relocatable and permanent modular buildings, the distribution analysis, and the analysis of the relationship between productivity and project size using SPSS statistical software. Chapter 5 comprises a concise summary and suggestions for future investigations pertaining to the specified research domain: The thesis concludes with the last chapter with a list of the references used.

# Chapter 2: Literature Review

## 2.1 Introduction

A comprehensive review of the literature has been conducted for this study, which involves peer-reviewed journals, publications, and industry reports. The sources include the American Society of Civil Engineers' (ASCE's) Journal of Construction Engineering and Management, Energy and Buildings, Journal of Management in Engineering, the Journal of Architectural Engineering, the Modular Building Institute magazines, and industry reports. To perform a literature review search, the author employed certain keywords, including construction productivity, relocatable, temporary, permanent, prefabricated, offsite construction, modular, and productivity metrics. To retrieve relevant data and literature, the author employed various search tools, such as Google search, Scopus, and the UNLV database. Ultimately, the author categorized the literature into eight distinct groups: 1) Current state of construction productivity, 2) Factors affecting construction productivity, 3) Factors affecting modular construction productivity, 4) Measurement and analysis of construction productivity, 5) Standardization impact on modular construction 6) Relocatable Modular Construction, 7) Permanent modular construction, 8) Types of building in modular construction. The subsequent chapter concludes with a concise overview of the literature study and the gap in the body of knowledge.

## 2.2 Current State of Construction Productivity

Labor productivity is critical to the United States' economic health, particularly in the construction industry (Allmon et al. 2000). However, “the current productivity rates are unacceptable, and the industry now as a whole is unsustainable” (Kluck and Choi 2023). Moreover, previous studies have often suggested negative productivity growth in construction (Sveikauskas et al. 2016). Compared to other sectors, since 1995, the annual growth rate of productivity for construction has merely risen by 1.0 %, in contrast, the manufacturing sector has realized an average economic surge of 3.6 % (Geiger et al. 2023; Mckinsey and Company 2017) There are many reasons and factors that contribute to this downward trend in construction productivity.

One of the primary reasons for the poor productivity in stick-built construction is due to the high level of customization. It is seen that higher levels of customization are associated with inefficiency and high costs, while standardization is associated with efficiency (Nahmens and Bindroo 2011). Thus, from the production and logistics point of view, the design choice should be restricted to achieve cost efficiencies (Blecker et al. 2005). This is especially true in the housing sector, where the builders aim to limit the level of choices to achieve economies of scale in the construction process (Blecker et al. 2005). For product customization can lead to disrupting the entire estimating, production, delivery and management process making the managing of operations difficult (Nahmens and Bindroo 2011).

The second reason would be the outdoor working environment in stick-built construction. This is because the construction industry is labor-intensive and physically demanding industry which often requires its workers to work for prolonged hours in the sun (Gillen and Gittleman 2010). Moreover, workers in outdoor high-temperature locations may experience a drop in productivity due to their natural tendency to reduce their physical activity to prevent excessive heat generation in their bodies (Kjellstrom et al. 2009). Furthermore, the consequences of working in high-temperature conditions reflect as delays, impatience, restlessness, and less excitement in regular duties (SAHU et al. 2013).

Another reason for this downward trend in productivity is “the reluctance by the construction industry to evolve” (Kluck and Choi 2023). While other sectors such as manufacturing had embraced lean processes to optimize their efforts, the construction industry was still fixated in the same production techniques used in the 1970s (Kluck and Choi 2023). Additionally, there has been a reduction of the actual “time on tools” that the skilled worker spends on the job site (Kluck and Choi 2023). This is due to the safety regulations which the workers must comply with, thus increasing the requirements placed on them in terms of the way they perform their work. Additionally, a study conducted by the source data from (Salem et al. 2005) states that 57 % of the work time is wasted in the construction industry, while 74 % of the worktime is utilized by the manufacturing industry. The same study by (Allmon et al. 2000) has identified defects, overproduction, waiting, non-used resources, transportation, inventory, motion and excess processing as reasons for the waste time in the construction industry. The diversity of factors influencing productivity underscores the need for a multifaceted approach to improving the sector's performance.

Perceptions of productivity trends vary widely among engineering academia, industry professionals, and economic researchers (Allmon et al. 2000), leading to conflicting conclusions about the state of construction productivity. For instance, data from the (Groningen 2006) suggests a significant plunge in US construction productivity over a 24-year period, while most other international construction markets experienced moderate to substantial growth. Conversely, the data from the Swedish Construction Federation indicates that the United States had one of the highest construction productivity performances among developed countries (Nasir et al. 2014) These contradictory findings highlight the challenges of accurately measuring and comparing construction productivity across different regions and time periods. Further complicating the picture, specific studies have produced divergent results. For example, (Harrison 2007) estimated an annual decline of 1.44% in US construction labor productivity between 1961 and 2005, while Canada experienced growth during the same period. This discrepancy between neighboring countries with similar economic structures raises questions about the factors driving these differences and the methodologies used to measure productivity.

While stick-built construction has struggled with productivity growth, the offsite construction industry presents a potentially different picture. Although specific statistics for offsite construction productivity are lacking (Assaad et al. 2023) related trends in the prefabricated home manufacturing sector show modest growth of 3.7 % per year on average between 2018 and

2023 (IBIS World 2024). This growth, while still slower than the overall economy and other US industries, suggests that offsite construction methods may offer some advantages in terms of productivity. The potential benefits of offsite construction are further supported by industry surveys, with about 90% of construction professionals reporting improved productivity, quality, and schedule certainty when using offsite methods compared to traditional construction (Bibeau et al. 2020)

In conclusion, the complex and often contradictory data on construction productivity highlights the need for more comprehensive and standardized measurement techniques. As the industry continues to evolve, particularly with the integration of offsite construction methods, there is an opportunity to address long-standing productivity challenges. Further research into the factors driving productivity differences between traditional and offsite construction could provide valuable insights for improving overall industry performance and contributing to broader economic growth.

## 2.3 Factors Affecting Productivity in Traditional Construction

The construction industry's productivity is influenced by a complex interplay of factors that vary across countries, job sites, and even within individual projects (Olomolaiye et al. 1998). Understanding these factors is crucial for improving productivity, yet researchers have yet to reach a consensus on how to categorize them effectively (Jarkas and Bitar 2012). This lack of agreement underscores the multifaceted nature of construction productivity and the need for a more unified approach to its analysis and improvement. There are five key factors which were found to affect the productivity in traditional stick-built construction: 1) non-availability of materials, 2) inadequate supervision, 3) skill shortage, 4) lack of proper tools/equipment and 5) poor communication. The following paragraphs explain these factors in more detail.

The non-availability of materials happens to be the top referred factor influencing construction productivity cited by several researchers such as (Abdul Kadir et al. 2005; El-Batreek et al. 2013; Enshassi et al. 2007; Ghoddousi and Hosseini 2012; Jarkas et al. 2012; Kaming et al. 1997; M. Jarkas et al. 2014; Soekiman et al. 2011; Soham and Rajiv 2013). The efficient supply of materials is a requirement for maintaining construction productivity. Conversely, poor material management results in the wasteful utilization of skilled workers, since it disrupts the momentum of the workforce (Hughes and Thorpe 2014; Jarkas and Bitar 2012; Thomas and Sudhakumar 2013). Insufficient supply of materials not only leads to periods of inactivity and exceeding budgeted costs (Kazaz et al. 2008), but also increases the level of demotivation among highly skilled workers (Jarkas and Radosavljevic 2013). There are several causes of non-availability of materials as lack of work planning and loss of materials on site, improper material usage to specification, difficulty in tracking materials, excessive paperwork for materials, poor transportation and storage, and poor procurement policy (Dai et al. 2007; Ghoddousi and Hosseini 2012; Mojahed and Aghazadeh 2008; Rodrigo A et al. 2011; Thomas and Sudhakumar 2013).

Inadequate supervision has been identified as the second most cited factor affecting labor productivity of construction by several researchers (El-Gohary et al. 2017; Heravi and

Eslamdoost 2015; Jarkas and Radosavljevic 2013; M. Jarkas et al. 2014; Rojas and Aramvareekul 2003; Soekiman et al. 2011; Thomas and Sudhakumar 2013). Having an incompetent manager diminishes workers' motivation and frequently leads to wasteful activities, subpar work or the need for redoing tasks, numerous unplanned breaks, and increased idle time of resources (Dai et al. 2007; Jarkas and Bitar 2012; M. Jarkas et al. 2014). It is also stated that inexperienced managers can hinder job progress, resulting in decreased labor productivity (Thomas and Sudhakumar 2013). Moreover, (Kazaz et al. 2008) discovered that the constant monitoring of workers might potentially decrease their overall productivity due to feelings of embarrassment and pressure caused by rigorous audits and various levels of on-site surveillance.

The third factor affecting the labor productivity of construction happens to be the skill shortage as cited by (El-Gohary et al. 2017; Jarkas and Bitar 2012; Kluck and Choi 2023; M. Jarkas et al. 2014; Soham and Rajiv 2013). The construction industry is said to be losing its skilled work workers as it is not considered “glamorous or appealing to these new younger people coming of work age” (Kluck and Choi 2023). The lack of competent craft workers and the unavailability of skill forepersons and supervisors have a negative impact on productivity (Dai et al. 2007). Contractors, whether local or international, typically prioritize short-term labor training owing to factors such as workload fluctuations, economic situations, and construction demand (El-Gohary et al. 2017; Jarkas and Bitar 2012). Consequently, inexperienced and inadequately trained workers typically generate subpar and defective output, frequently necessitating costly rework (Jarkas and Bitar 2012; M. Jarkas et al. 2014). Therefore, training and developing skilled labor has remained a challenge for construction companies (Hasan et al. 2018). However, the key to achieving productivity increases is in the proper utilization of skills, rather than just increasing the supply of skills (Abdel-Wahab et al. 2008).

The fourth factor happens to be lack of proper tools/equipment which has been cited by several researchers such as (Dai et al. 2007; El-Batreek et al. 2013; Ghoddousi and Hosseini 2012; Ng et al. 2004; Rodrigo A et al. 2011; Soekiman et al. 2011; Thomas and Sudhakumar 2013). Equipment shortages are said to be causing major idle times at construction sites (Abdul Kadir et al. 2005). Prior research has identified various factors that contribute to low productivity in construction projects. These include outdated and obsolete construction equipment, inadequate supply of tools, scarcity of spare parts, inadequate service and maintenance, underutilization of machinery, unavailability of equipment, restrictive project policies regarding consumables, subpar equipment maintenance, slow equipment repairs, improper maintenance of power tools, and inefficient operators (Dai et al. 2007; Ng et al. 2004; Rodrigo A et al. 2011). A significant issue seen on construction sites was the inadequate supply of vehicles for transporting tools (Rodrigo A et al. 2011).

The final factor which affects the construction labor productivity happens to be poor communication. Poor communication has been cited as one of the topmost factors impeding construction productivity by several researchers such as (Heravi and Eslamdoost 2015; Hughes and Thorpe 2014; Jarkas and Bitar 2012; Naoum 2016; Rojas and Aramvareekul 2003; Thomas and Sudhakumar 2013). Insufficient communication on building sites is a primary factor contributing to low motivation and productivity (Hasan et al. 2018). Efficient communication is crucial for the effective execution of a construction project (Thomas and Sudhakumar 2013). Inadequate communication can result in misinterpretation or misunderstanding of technical details and site management instructions, and this can lead to various problems on construction sites, including delays in decision-making, shortages of resources, frequent design changes, mistakes, and the need for rework (Jarkas and Bitar 2012; Mahamid 2013).

Thus, it can be concluded that factors like 1) non-availability of materials, 2) inadequate supervision, 3) skill shortage, 4) lack of proper tools/equipment and 5) poor communication can impact the productivity of construction.

## 2.4 Factors Affecting Productivity of Modular Construction

The topic of labor productivity in the construction business is complex, with elements that influence it differing greatly between traditional stick-built methods and offsite construction operations (Assaad et al. 2023). There are studies related to factors affecting the productivity of stick-built construction, however, these factors might not be applicable to modular construction. An extensive study has been carried out on the productivity of stick-built construction. However, the results of this research may not be immediately relevant to offsite construction since modular and prefabricated building technologies have distinct methods (Assaad et al. 2023; Chen and Samarasinghe 2020; Durdyev and Ismail 2019).

The working conditions are a notable difference between traditional and offsite buildings. Offsite construction facilities provide controlled environments and scheduled timetables (AIA (The American Institute of Architects) 2019), thereby reducing the negative effects of severe weather conditions that significantly hinder production in conventional construction (Hasan et al. 2018; Ibbs and Sun 2016; Kisi et al. 2020; Pereira et al. 2020). The regulated atmosphere not only mitigates weather-related disturbances but also fosters a more consistent and potentially more efficient work process (AIA (The American Institute of Architects) 2019; Assaad et al. 2023). Offsite construction, with its manufacturing-like characteristics, brings about a unique set of elements that impact productivity, which differ from those seen at regular construction sites (John et al. 2022).

Offsite construction exhibits notable differences in terms of the nature of work (John et al. 2022), and working conditions of workforce (Arif and Egbu 2010). Offsite construction tasks typically have similarities to industrial production lines (John et al. 2022), which are characterized by increased degrees of automation and digitalization. This shift affects the type of skills required by the workforce, moving away from traditional trade-specific skills towards more technologically oriented skills (Ginigaddara et al. 2022). In addition, the controlled atmosphere of offsite facilities changes the safety conditions, leading to a distinct set of difficulties and risks in contrast to conventional construction sites (Fard et al. 2017). The inherent disparities highlight the necessity for a customized strategy for comprehending and enhancing productivity in offsite construction.

Although there are parallels in the process of finding productivity factors in stick-built and offsite construction, a new study emphasizes the distinct obstacles encountered by the offsite industry. In a study done by (Assaad et al. 2023), the researchers found the five main characteristics that have a negative impact on labor productivity in modularization. The following issues exists: untrained personnel, inadequate training, poor logistics, errors that result in rework, work area congestion, and insufficient coordination. These findings offer useful insights into the precise areas that need focus in efforts to enhance productivity in offsite construction.

Additionally, critical success factors (CSFs) of modularization have been identified by (O'Connor et al. 2014) which drive the modularization success. The authors identified 21 CSFs and they are: module envelope limitations, alignment on drivers, owners planning resources and processes, timely design freeze, early completion recognition, preliminary module definition, owner-furnished/long lead equipment specifications, cost savings recognition, contractor leadership, contractor experience, module fabricator capability, investment in studies, heavy lift/site transport capabilities, vendor involvement, operations and maintenance provisions, transport infrastructure, owner delay avoidance, data for optimization, continuity through project phases, management of execution risks, and transport delay avoidance. Similarly, a study was conducted which identified the barriers of implementing modular techniques in Hong Kong, of which 21 barriers were identified and ranked. The top three identified barriers in the study were: (1) urban site (site access and on-site storage area), (2) transportation or logistics, and (3) distance from factory to site (Choi et al. 2019).

Although there have been notable improvements in comprehending the productivity of offsite construction, there are still substantial research gaps. There have been limited attempts to measure the relative significance of specific elements that affect worker productivity in offsite construction projects (Dai et al. 2009). This lack of prioritization hinders the development of targeted strategies to enhance productivity in the offsite sector. As the construction industry continues to evolve and embrace offsite methods, addressing these research gaps becomes increasingly crucial for optimizing productivity and realizing the full potential of modular and prefabricated construction techniques.

## 2.5 Measurement and Analysis of Construction Productivity

Accurate measurement and evaluation of productivity are vital for effective project management and continual improvement in modular buildings. Regrettably, the Bureau of Labor Statistics (BLS) does not provide any official productivity metrics for the construction industry. This is mostly because there is a dearth of appropriate data available for such measurements (Huang et al. 2009) Measuring productivity in the construction sector is a difficult task, and ongoing efforts are being made to create programs for collecting and analyzing data to improve these efforts (Allmon et al. 2000; Eastman and Sacks 2008). Labor productivity in the industry is often described by professionals using concepts like gross output-based labor productivity (Harrison 2007). However, a single industry level productivity measure alone is not sufficiently informative (Huang et al. 2009). One approach would be to focus on products, such as developing productivity measures for different building types or infrastructure types (Huang et al. 2009). According to this approach, three specific methods for measurement of labor productivity can be grouped as follows: 1) focus on building types, gross output, 2) focus on building types, value added, 3) focus on infrastructure type, value added.

Firstly, when considering different types of buildings, a useful way to assess productivity in construction could be the total area of the project in square feet (Huang et al. 2009). Utilizing square footage as a metric for output circumvents the issue of inadequate output deflators, which are metrics and tools used for measurement (Huang et al. 2009). In this approach, the data for the labor input is taken as the "number of construction workers", which can then be combined with the average weekly hours of production workers to get an estimate of the annual hours (Huang et al. 2009).

The second approach is the "focus on building types, value added". In the following approach the output of establishments and the labor input both are associated with payrolls (Huang et al. 2009). In the following case, economic consensus asks individuals about the percentage dollar value of work done by different building types (Huang et al. 2009) and value is added to the individual establishments. The "Value added for the construction industry is defined as the dollar value of business done less costs for construction work subcontracted to others and payments for materials, components, supplies, and fuels (United States Census Bureau 2002). Moreover, the labor input is calculated in a similar approach to the "focus on building types, gross outputs".

The last approach would be “focus on infrastructure type, value added”. In this approach, rather than focusing on one building type, the focus is on the infrastructure type. For instance, under the category “Heavy and Civil Engineering Construction,” the focus would be on “highway and street construction,” which includes both general contractors and specialty trade contractors who work in this area (Huang et al. 2009). The labor input in this approach is taken from the (United States Census Bureau 2002) obtaining the total number of employees and average weekly hours of production workers in the infrastructure type (Huang et al. 2009). Therefore, the following three approaches can be used in the measurement of labor productivity.

The integration of off-site construction methods, such as prefabrication, into traditional on-site activities has been a subject of significant research interest, with scholars like Eastman and Sacks exploring its potential impact on construction productivity. (Eastman and Sacks 2008) have undertaken research on several similar activities that take place both on-site and off-site. Research has shown that activities performed outside of the workplace tend to demonstrate higher levels of productivity in comparison to activities carried out within the workplace. The authors argue that the value of construction productivity is underestimated and suggest that the evaluation of building productivity should include the production of prefabricated materials. The concept of construction worker productivity, as suggested by the study (Eastman and Sacks 2008) relies on gross output measurement. External processes, such as prefabrication, contribute to enhanced productivity. The integration of these elements into a construction project is expected to improve worker productivity, as measured by total output. Nevertheless, the implementation of prefabrication is not expected to affect worker productivity, as assessed by value added, according to the study (Harrison 2007). The discrepancy between production definitions and the assumed scope of the construction sector can lead to different estimations and contribute to divergent perspectives on industry productivity trends (Huang et al. 2009).

## 2.6 Standardization Impact on Modular Construction

Standardization is defined as “the development and use of consistent designs for regularity and repetition” (Kluck and Choi 2023). Standardization has several benefits in the construction industry. Such as standardization has been effective in cost savings, increasing project efficiency and productivity, while also increasing quality and safety (Choi et al. 2022; Gibb 2001). In the concept of modularization, the combination of standardization and modularization is not new (O’Connor et al. 2015). Standardization offers several advantages for modularization as well. O’Connor et al. (2015) identified ten advantages in modularization, which are design only once and reuse multiple times; design and procure in advance/respond to schedule needs; parallel engineering for site adaptation; learning curve benefits in fabrication; procurement discounts from volume or early commitment; construction material management cost savings; learning curve benefits in module installation/site construction; learning curve in commissioning and start-up; learning curve benefits in operations and maintenance (O&M) and O&M material management cost savings.

The learning curve effect with the help of standardization has seen several benefits in modularization. The “learning phenomenon is understood as a process of acquiring experience during performing some similar jobs, in consequence leading to improving skills of a processor" (Janiak and Rudek 2008). This decreases the time required to perform the next job (Janiak and Rudek 2008). In modularization, learning curve comes with the benefit of duplicating efforts (Kluck and Choi 2023). For example, if everyone associated with the project has gone through the project development this results in an optimization of everyone's efforts and an increase in the efficiency of the second and subsequent projects (Kluck and Choi 2023). This learning curve effect has advantages in several phases of modular construction such as commissioning/start up, fabrication, module installation/site construction, and operations and maintenance (O'Connor et al. 2015).

## 2.7 Permanent Modular Construction

Modular construction is a versatile method that may be employed in various contexts, such as residential, commercial, and industrial settings (Modular Building Institute 2023a). Commercial modular buildings consist of two distinct divisions: permanent modular buildings and relocatable modular buildings. Each type includes a wide variety of project types that have unique characteristics, advantages, and obstacles. The Modular Building Institute exclusively concentrates on the business facet of the sector. According to the (Modular Building Institute 2023a), commercial buildings are factory-built components and structures that are not intended for domestic use. These buildings are designed to comply with all relevant building codes.

Permanent modular construction (PMC) is a modern and eco-friendly approach that involves using offsite manufacturing techniques to create prefabricated building pieces. These sections can be single-story or multistory and are delivered as complete modules (Modular Building Institute 2023a). PMC covers a wide range of project types, such as multifamily housing, dormitories, healthcare facilities, educational institutions, retail outlets, and office complexes. PMC can be fabricated using timber, steel, or reinforced concrete.

Permanent modular construction (PMC) has numerous benefits. PMC can be proficiently utilized in regions affected by natural catastrophes or prone to frequent occurrences of such events (Hořínková 2021). According to the Construction Industry Institute, the implementation of PMC results in a construction cost that is 10-15% lower than conventional methods (Hořínková 2021). The lifting mechanism utilized in PMC is more time-efficient, resulting in reduced lease expenses and maintenance costs (Hořínková 2021) PMC is a more secure alternative to conventional stick-built construction (Klakegg 2013). Moreover, according to (Klakegg 2013), the number of accidents in PMCs is reduced by 80% compared to conventional buildings. In addition, (Becker et al. 2003) conducted a study using questionnaires to poll PMC specialists. The results indicated that 50% of these experts considered PMC to be a safer method of building when compared to conventional construction.

Permanent modular construction also results in reduced waste. The study conducted by (Lawson et al. 2012) demonstrates that PMC has the potential to achieve a significant reduction of up to 70% in waste output. Permanent modular construction (PMC) has a higher capacity for waste management in comparison to traditional approaches, including those used inside building sites (Hořínková 2021). Permanent modular construction (PMC) eliminates the need for constantly supplying construction materials to the building site, resulting in a reduction in fuel consumption by vehicles and thus decreasing air pollution produced by vehicle operation (Kantová and Motyčka 2014). (Quale et al. 2012) demonstrated that modular building methods have reduced environmental consequences when compared to on-site construction, leading to approximately 30 percent lower greenhouse gas emissions. Hence, PMC is an appropriate remedy for addressing the requirement of waste reduction, as supported by the studies conducted by (Kawecki and Bashford 2010), (Lawson et al. 2012), and (Illankoon and Lu 2020).

Undoubtedly, permanent modular construction presents numerous benefits, but it also involves challenges and drawbacks. Design restrictions are a significant concern. High-rise construction faces a perceived deficiency in strong structural systems and connecting techniques that guarantee the structural integrity, overall stability, and robustness of a fully modular building (Thai et al. 2020). Another drawback is the substantial upfront expense. Offsite construction, despite having lower construction costs, necessitates the installation of a manufacturing unit (Ferdous et al. 2019). The initial capital investment for modular construction might be substantial because of the requirement for specific designs, the establishment of manufacturing facilities, and transportation logistics (Mohammad et al. 2016). By utilizing the benefits of PMC, such as accelerated construction schedules, minimized material wastage, and enhanced safety measures, while actively tackling the difficulties associated with different project types, including expensive upfront costs, intricate designs, and adherence to building codes, stakeholders can maximize efficiency and take full advantage of this pioneering construction method.

## 2.8 Relocatable Modular Construction

Relocatable Modular Construction (RMC) provides a flexible and adjustable option for projects that necessitate temporary or portable structures. The International Existing Building Code defines relocatable buildings (RB) as partially or completely assembled buildings that are designed to be reused multiple times and transported to different building sites (Modular Building Institute 2023b) These constructions are mostly designed for temporary or semi-permanent use and have a very short lifespan of 15 to 30 years due to the choice of materials rather than artistic considerations (Mapston and Westbrook 2010). Relocatable structures provide services to a wide range of customers, including general contractors, real estate developers, manufacturers, commercial businesses, education providers, and financial institutions in the resource industry (Modular Building Institute 2023b). Various types of projects, including education, healthcare, general administrative and sales offices, commercial and retail, security, equipment storage, and emergency and disaster relief, employ relocatable modular construction.

Relocatable modular building has numerous benefits in comparison to stick-built modular construction. Relocatable modular structures are characterized by their adaptability and capacity for reuse (MBI 2011). Relocatable modular buildings (RMBs) have the distinct advantage of being able to be reused in many locations without being limited to a specific site (MBI 2011).

Another benefit of RMB is its ability to be quickly and easily deployed. Relocatable buildings that comply with building code standards can be rapidly deployed during significant natural disasters. These structures can be utilized to provide sanctuary, healthcare facilities, and educational spaces, contributing to the restoration of a sense of normalcy among the impacted populace (MBI 2011). Furthermore, construction-site trailers are frequently employed as conventional site offices in the industry since they are readily accessible and can be promptly delivered to construction sites and facilities (Modular Building Institute 2019). According to (Jackson 2015), the reason for choosing RMC solutions over permanent construction is typically linked to the belief that this sort of structure can provide the necessary accommodations and facilities of a permanent building quickly, cost-effectively, and with flexibility. Relocatable modular buildings are employed to tackle housing issues caused by population growth, thanks to its reusable and adaptable design characteristics (Modular Advantage Magazine 2022).

While relocatable modular construction (RMC) offers various benefits, it also presents certain obstacles associated with relocatable modular buildings. Handling issues, potential overturning, and external body corrosion were identified as challenges associated with relocatable modular buildings by (Kamali and Hewage 2016). A study was done by (Kalutotage and Waidyasekara 2022) modular buildings for construction site offices to identify the main obstacles faced by contractors while implementing Relocatable Modular building (RMB) technology. This study involved conducting interviews from the contractor's perspective. It was evident from the study that inadequate management of construction site offices, namely those using container-based Relocatable Modular Buildings (RMB) technology, is a significant obstacle due to its unfavorable reputation (Kalutotage and Waidyasekara 2022). Other issues that were highlighted include the occurrence of electric shock during the use stage and the significant initial cost associated with relocatable modular buildings. Overall, relocatable modular construction offers an adaptable and rapidly deployable solution for temporary facilities across many industries. While providing flexibility, cost-effectiveness, and the ability to address urgent needs, challenges remain around negative perceptions, handling difficulties, and potentially higher initial costs. As the modular construction industry continues to evolve, addressing these issues will be key to further realizing the benefits of this innovative building approach.

## 2.9 Types of Building in Modular Construction

Modular construction, both permanent and relocatable, encompasses a diverse range of applications across various industries. This study primarily focuses on ten key types: multifamily housing, retail, office, education, healthcare, dormitory, assembly, special applications, correctional facilities and bathroom pods. Each of these types serves distinct purposes and contributes uniquely to the modular construction market.

Education stands out as a significant sector in modular construction, defined as "structures designed and constructed for educational purposes." (Modular Building Institute 2023c). These buildings cater to a wide spectrum of educational institutions, from K–12 schools to universities, and include classrooms, administrative buildings, and other education-related facilities (Modular Building Institute 2023c). According to the (Modular Building Institute 2023a) report, education-related projects accounted for 15.6% of the total permanent modular construction market in 2022, with an average project size of 18,424 square feet comprising 32 modules. The education sector's prominence in modular construction is further emphasized by school districts across North America collectively owning approximately 200,000 relocatable classroom units (Modular Building Institute 2023b), highlighting the adaptability and efficiency of modular solutions in meeting educational infrastructure needs.

Multifamily housing represents the largest segment of the modular construction market, defined as "structures designed to house individuals or families in multiple separate units" (Modular Building Institute 2023c). The industry has witnessed substantial growth in this category, with its permanent modular construction market share increasing from 21% in 2020 to 32.3% in 2022 (Modular Building Institute 2023a). On average, multifamily housing projects were completed in 380 days, spanning four stories and 59,718 square feet, with 81 modules per project (Modular Building Institute 2023a). This rapid growth underscores the increasing adoption of modular construction techniques to address housing demands efficiently.

The office sector follows as the second-largest category in permanent modular construction, accounting for 19.1% of projects. Defined as "structures designed and constructed for non-education, nonretail administrative applications," (Modular Building Institute 2023c) office projects averaged 8,883 square feet with 14 modules, completed in an average of 296 days in the market of permanent modular construction. The versatility of modular office spaces is particularly evident in their ability to accommodate temporary expansions of existing facilities without permanent alterations (Modular Building Institute 2023b), making them ideal for fluctuating business needs.

Retail and healthcare sectors, while smaller in market share, play crucial roles in the modular construction landscape. Retail projects, designed for face-to-face interaction with the public, represented 4.8% of permanent modular construction in 2022, with an average size of 2,103 square feet and 4.5 modules per project (Modular Building Institute 2023a). Healthcare facilities, ranging from doctor's offices to hospital extensions, constituted 5.3% of the market share (Modular Building Institute 2023a). The COVID-19 pandemic highlighted the critical need for rapidly deployable medical facilities, further emphasizing the importance of modular construction in healthcare.

Other categories explored in this study include dormitories, workforce housing, assembly structures, correctional facilities, and special application buildings. Each of these categories serves specific needs, from providing accommodation for students and remote workers to creating spaces for public gatherings and specialized detention facilities. The diversity of these applications demonstrates modular construction techniques' adaptability and wide-ranging potential across various sectors.

In conclusion, the modular construction industry continues to evolve and expand its reach across multiple sectors. From education and housing to healthcare and specialized facilities, modular construction offers efficient, adaptable, and rapid solutions to meet diverse infrastructure needs.

As the industry grows, it is likely to play an increasingly significant role in shaping the future of construction across all sectors.

## 2.10 Summary of Literature Review

The construction industry's productivity has been a subject of significant debate and research, with conflicting data and interpretations complicating the assessment of its performance. Traditional construction methods have shown stagnant or declining productivity over the past decades. These challenges are further compounded by the lack of standardized metrics and official productivity measures from the Bureau of Labor Statistics. In response, the industry has begun exploring alternative approaches, with modular construction emerging as a promising solution. Modular construction, encompassing both permanent and relocatable structures, offers benefits such as reduced construction costs, improved safety, and decreased waste output. Permanent Modular Construction (PMC) has shown potential to reduce costs by 10-15% compared to conventional methods, while Relocatable Modular Construction (RMC) provides flexibility and rapid deployment capabilities (Modular Building Institute 2023a; b). Standardization also provides several benefits to modularization in different phases and leads to the learning curve effect where the efficiency and productivity is increased.

The modular construction market spans diverse categories including multifamily housing, education, office spaces, retail, and healthcare facilities. Multifamily housing has seen substantial growth, increasing its market share in permanent modular construction from 21% in

2020 to 32.3% in 2022, while education-related projects accounted for 15.6% of the total permanent modular construction market in 2022 (Modular Building Institute 2023a). Despite challenges such as design restrictions and upfront expenses, the growing adoption of modular techniques across various sectors suggests a shift towards more efficient and adaptable construction practices. This ongoing investigation about finding out the productivity in different categories in modular construction would help identify and overcome the productivity challenges. This exploration and development of modular construction techniques have the potential to address long-standing productivity issues in the construction industry, paving the way for more efficient and sustainable building practices.

## 2.11 Gap in the Literature

The literature review reveals a significant gap in the understanding of productivity within the modular construction industry, particularly across its various categories. While extensive research has been conducted on productivity in traditional construction methods, and the overall benefits of modular construction have been documented, there is a notable absence of studies specifically highlighting the productivity in different modular building types, such as multifamily housing, education, office spaces, retail, and healthcare facilities. This gap is particularly significant given the growing adoption of modular techniques in these diverse sectors. The lack of category-specific productivity studies limits our understanding of how modular construction performs in different contexts and hinders the development of targeted strategies for improvement. Addressing this gap through focused research on productivity across various modular construction categories would provide valuable insights for industry practitioners, policymakers, and researchers, potentially leading to more efficient and effective implementation of modular construction techniques across the industry.

# Chapter 3: Methodology

## 3.1 General Research Outline

The research was carried out according to the steps illustrated in figure 1. The steps of the research are described in the following sections.

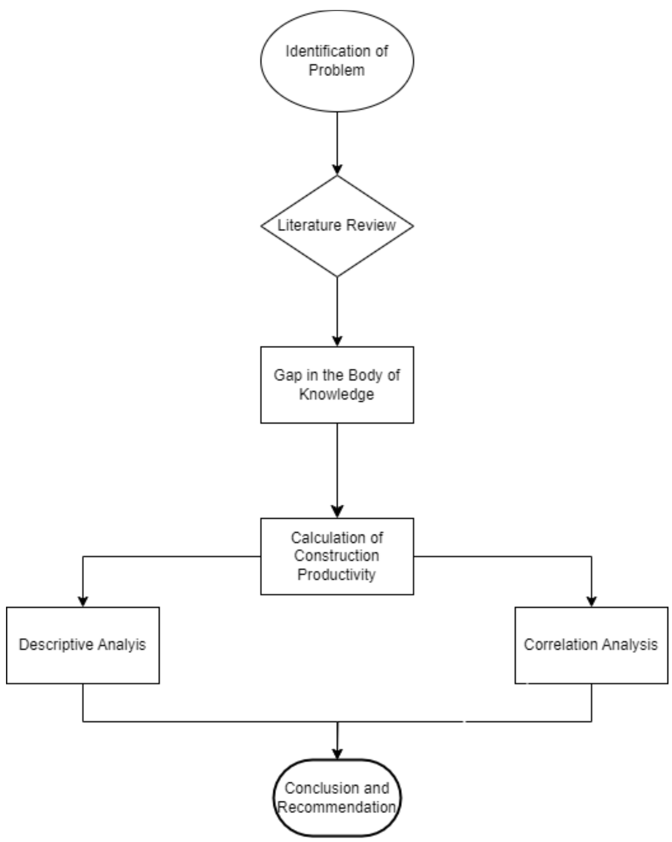



Figure 1. Research Methodology Flowchart

## 3.2 Identification of Problem and Literature Review

The initial stage of the investigation involved the identification of the problem. This was accomplished by finding a gap in the existing body of literature. The literature assessment has identified two crucial research needs: 1) There is a requirement to gain a deeper comprehension of the patterns and trends in productivity (the total amount of work completed per day) in different project categories (such as multifamily, dormitory, correctional, health, education, retail, office) within the modular building industry. 2) Additionally, there is a need to examine the relationships between the total amount of work completed per day (productivity) and the size of the project within various project categories. The literature review identified and discussed the following topics: a) Current state of construction Productivity b) Factors affecting construction productivity c) Factors affecting productivity of modular construction d) Measurement and analysis of construction productivity e) Permanent modular construction f) Relocatable modular construction g) Categories in modular building construction.

## 3.3 Identification of Data and Data Source

Following the literature review, the specific data required to meet the research objectives were determined and the appropriate source was selected. The data to be collected includes:

1. The project name, the location of the project, the type of building, the type of modular construction, and the name of the fabricator have been collected.

2. The total project size of modular projects was also collected.

3. The duration needed to finish projects were also collected.

4. This study calculated the productivity of modular construction projects by dividing the gross size of the project with the number of days required for completion across different project categories.

5. The productivity calculated was used to conduct the correlation analysis with gross size of project.

6. The characteristics of the projects (project name, location, type of building, type of modular construction and fabricator name) were used to conduct descriptive analysis.

Once the specific data needed for the study was determined, the source of the data was also determined. The data was acquired from the Modular Building Institute database (Modular Building Institute 2024) , which included all the relocatable and permanent modular structures in the United States. The Modular Building Institute (MBI) is a global non-profit trade group dedicated to promoting modular construction. It was established in 1983 (Modular Building Institute 2024). The MBI consists of manufacturers, constructors, and dealers involved in both permanent and relocatable buildings. The primary objective of the MBI is to promote the adoption of offsite and modular building by employing new construction methods, engaging with the construction community and customers through outreach and education, and acknowledging exceptional modular designs and facilities. The website link provided is (Modular Building Institute 2024). The data was collected from the Modular Building Institute database on January 7th, 2024. A total of 303 project data from the permanent modular building and 188 project data from the relocatable modular construction were collected. The data which were collected comprised of the characteristics of the modular projects, with this study mainly focusing on two variables the gross size of the project and the number of days required for completion of the projects. However, there was no information in the database regarding the timespan the dataset was distributed.

## 3.4 Calculation of Modular Construction Productivity

The concept of productivity in construction is not uniformly defined due to the industry's diversity and varying research objectives. Definitions range from value added per worker at the state level (Kinfemichael and Morshed 2019) to the ratio of output over input in a productive system (E. Bernold and M. AbouRizk 2010). Industry practitioners tend to define labor productivity in concepts like the gross output-based labor productivity (Eastman and Sacks 2008). In this study the productivity was determined by dividing the total area of the project (measured in square feet) by the time taken (measured in days) to complete each category for both relocatable and permanent modular construction. The duration of completion was calculated by subtracting the production date from the occupancy date. An effort was made to contact the Modular Building Institute (MBI) to obtain a clear understanding of the term "number of days required for production," but unfortunately, we were unable to reach them to confirm.

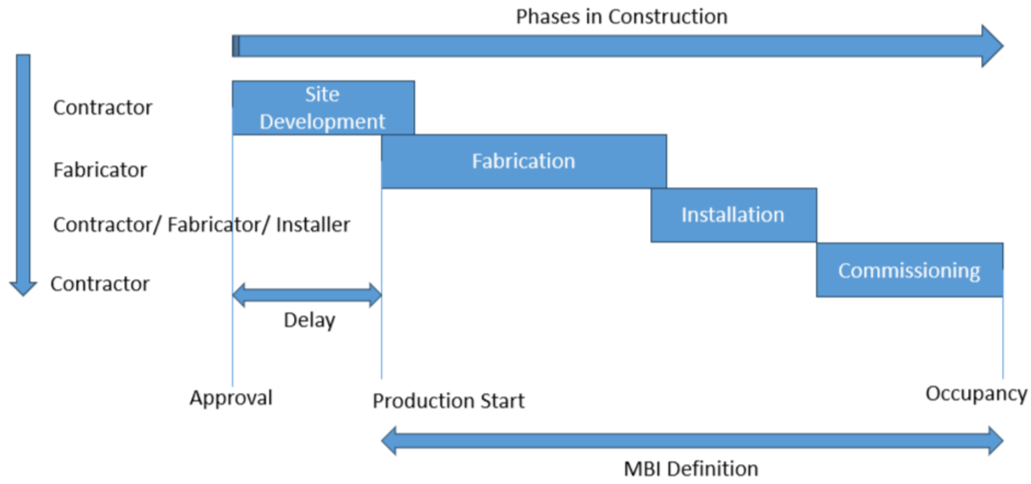



Figure 2. Different Phases in Modular Construction

The time span between the date of production and the date of occupation includes many stages of construction, which can be classified based on the viewpoints of manufacturers, contractors, and owners. These phases frequently coincide and might happen simultaneously, depending on the project needs and timetable. The precise time and order of these phases may differ depending on factors such as project intricacy, site circumstances, and regulatory mandates. The duration can also vary as the fabrication can concurrently happen while sitework is done, and depending on the level of concurrency, it can impact the duration. Additionally, it is also to be noted that the date of approval (notice to proceed) and the production start date can be the same or different. This will have an impact on the duration of the project significantly. In this study, due to limitations in available data, we assumed the number of days required for completion to be the difference between the occupancy date and the production date. It's important to note that this assumption may not capture all the nuances of the construction process, but it provides a consistent metric for comparison across projects.

## 3.5 Data Analysis

The data analysis is mainly divided into two sections 1) the characteristics of modular projects which is further subcategorized into frequency of modular projects, size of modular projects, and productivity of modular projects, 2) the correlation analysis which is categorized into distribution analysis, Kendall's tau-b and linear regression analysis.

### 3.5.1 Characteristics of Modular Projects

The following section explores the frequency of modular projects, the size of modular projects and the productivity of modular projects.

#### 3.5.1.1 Frequency of Modular Projects

The initial phase of study involved creating bar charts to visually represent the frequency distribution of projects. Bar charts were employed to depict the frequency distribution of projects among different modular building types, such as multifamily, dormitory, correctional, health, education, retail, and office, for both permanent modular construction (PMC) and relocatable building (RB) projects. The frequency of modular projects was explored by relocatability, building type and by the location.

#### 3.5.1.2 Size of Modular Projects

In the second stage of study, key metrics such as mean, median, interquartile range, minimum and maximum values were calculated for productivity gross size of the modular projects in each category of relocatable and permanent modular construction to explore the size of modular projects by relocatability. Additionally, the size of the modular projects by building type were also explored with the modular projects ranked in terms of the median size of the projects in each building type for both permanent and relocatable modular projects. Moreover, the top ten modular buildings in terms of size were also tabulated in this section.

#### 3.5.1.3 Productivity of Modular Projects

In the second third part of this study, explores the key metrics such as mean, median, and interquartile range were calculated for productivity (the gross size of project finished per day) in each type of modular building for relocatable and permanent modular construction. In this case, similarly to section 3.5.1.2, the productivity of modular projects was explored by building types, and the top 10 modular buildings in terms of productivity were tabulated.

### 3.5.2 Correlation Analysis

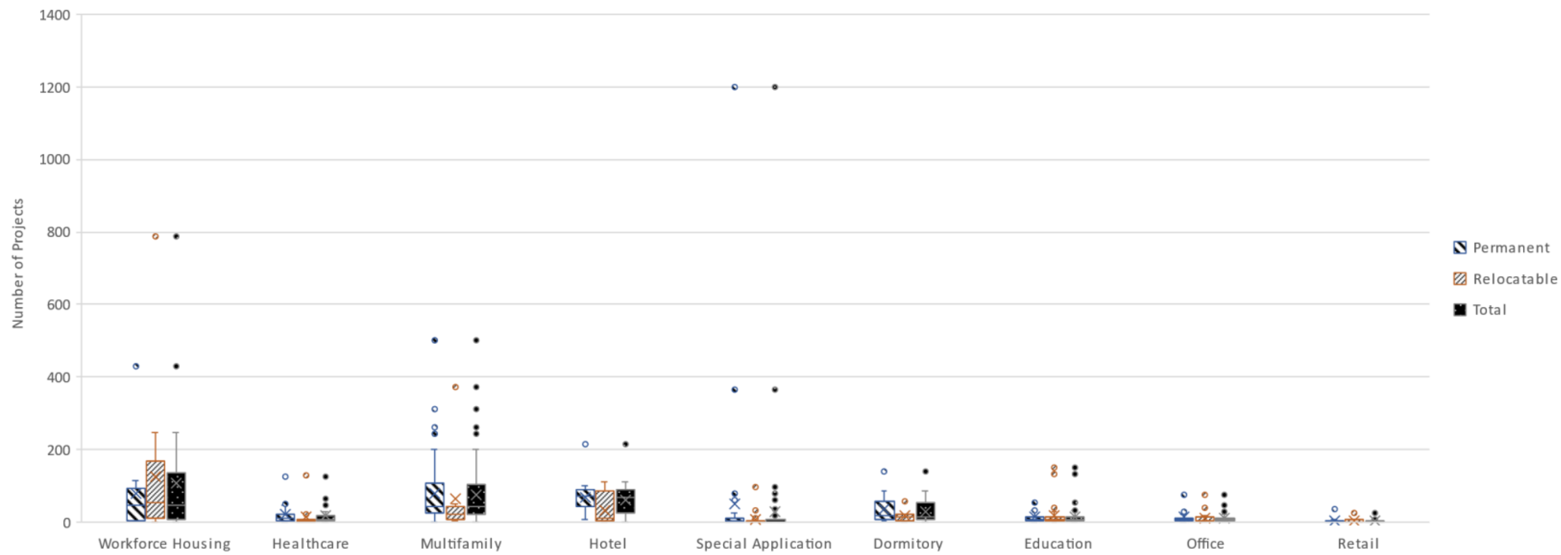
The following section explores the distribution analysis, cleaning of data for outlier, Kendall's Tau-B analysis and the linear regression of the modular projects.

#### 3.5.2.1 Distribution Analysis

In this step, we visually represented the distribution of productivity and gross project size for distinct project types. This was done separately for permanent and relocatable modular construction. This will aid in the identification of possible anomalies and the evaluation of the disturbance of the data within each category.

#### 3.5.2.2 Cleaning of Data for Outlier

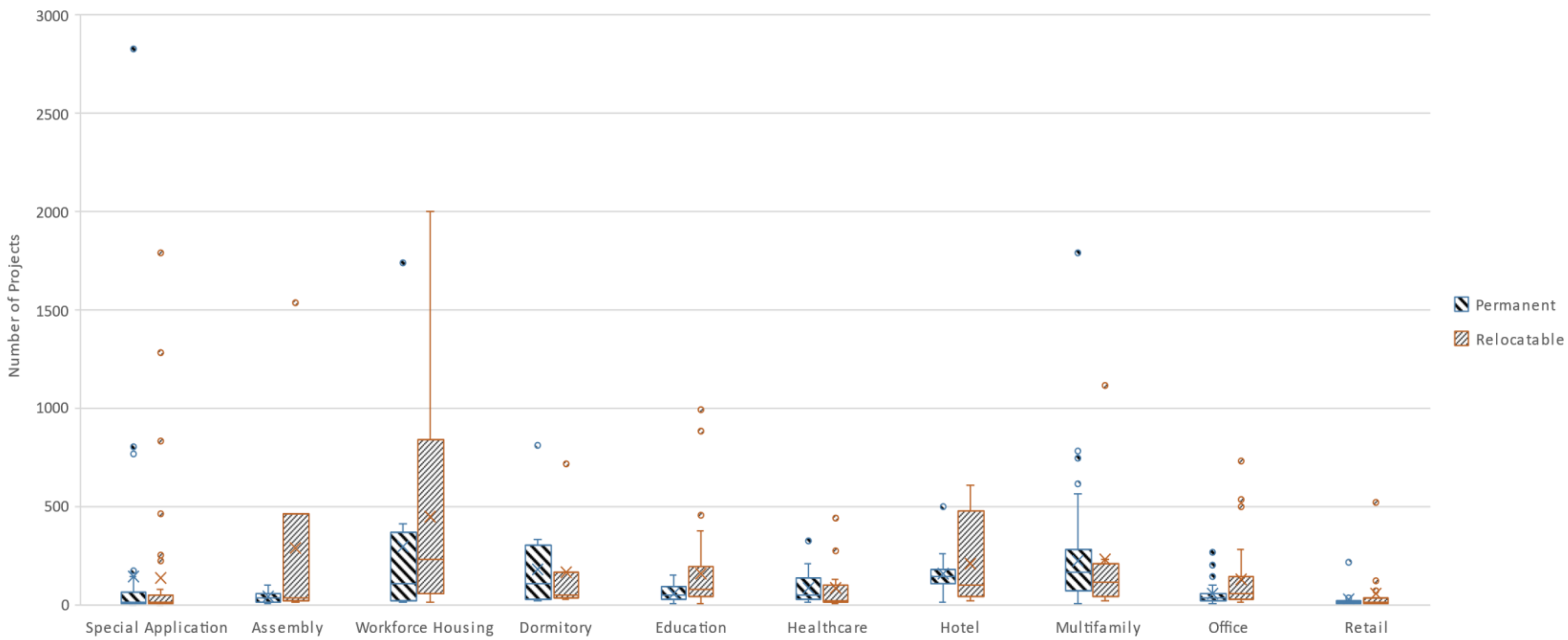
This involved the cleaning and processing of the data obtained from the Modular Building Institute database. In this case, the data obtained for both the permanent and relocatable modular building were processed and cleaned off any outlier. The process involved identifying the major outliers from the box and whisker plot for all the categories for the productivity and for the gross size of the project for both relocatable and permanent modular buildings. The outliers identified were based on the box and whisker plots, with the outliers being outside the whiskers of each box. The major outliers once identified were then removed from the dataset to make sure it is clean to be analyzed in the SPSS software for the correlation and regression analysis. Figure 2 and Figure 3 below, shows the box and whisker plot for the construction productivity for the permanent and relocatable building, and for the box and whisker plot for the gross size of the project for both the permanent and relocatable modular building




| | Workforce Housing | | | Healthcare | | | Multifamily | | | Hotel | | | Special Application | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PMC | RMC | Total | PMC | RMC | Total | PMC | RMC | Total | PMC | RMC | Total | PMC | RMC | Total |
| Minimum | 3.2 | 0.904 | 0.904 | 1.75 | 0.049 | 0.049 | 0.525 | 3.2 | 0.525 | 6.867 | 0 | 0.495 | 0.162 | 0.076 | 0.076 |
| Q1 | 4.667 | 10.192 | 7.48 | 5.05725 | 1.432 | 2.88 | 23.875 | 8.829 | 21.73 | 42.669 | 3 | 23.68 | 0.82425 | 0.32 | 0.4525 |
| Median | 47 | 53.025 | 48.413 | 10.419 | 2.465 | 6.8 | 43.2 | 22.763 | 42.52 | 72 | 12 | 67 | 2.756 | 1.144 | 1.8645 |
| Mean | 79.527 | 126.327 | 106.8 | 20.58646 | 13.892 | 18.01 | 77.74945 | 65.1 | 76.47 | 66.678 | 34 | 61.85 | 51.5735 | 6.049 | 28.88 |
| Q3 | 93.722 | 167.524 | 134.8 | 23.4 | 7.68 | 19.8 | 105.818 | 44.894 | 102.34 | 89 | 87 | 89 | 11.14425 | 3.332 | 16.15 |
| Maximum | 116.252 | 248.915 | 248.915 | 45.377 | 7.68 | 28.7 | 200 | 51.479 | 200 | 100.2 | 111 | 110.93 | 23.508 | 5.617 | 19.375 |
| IR | 89.055 | 157.332 | 127.32 | 18.34275 | 6.248 | 16.92 | 81.943 | 36.065 | 80.61 | 46.331 | 84 | 65.32 | 10.32 | 3.012 | 15.6975 |

| | Dormitory | | | Education | | | Office | | | Retail | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PMC | RMC | Total | PMC | RMC | Total | PMC | RMC | Total | PMC | RMC | Total |
| Minimum | 4.032 | 1.873 | 1.873 | 0.77 | 0.059 | 0.059 | 0.216 | 0.896 | 0.216 | 0.32 | 0.31 | 0.31 |
| Q1 | 9.024 | 2.24 | 7.404 | 4.81125 | 3.473 | 4.545 | 2.63624 | 2.88 | 2.88 | 0.9 | 0.525 | 0.864 |
| Median | 17.28 | 15 | 15.67 | 8.6285 | 8.996 | 8.996 | 6.57 | 5.04 | 6.45 | 2.282 | 1.52 | 2.1 |
| Mean | 35.917 | 17.406 | 30.52 | 13.9152 | 17.014 | 15.53 | 13.08771 | 10.855 | 12.03 | 4.149 | 5.42075 | 4.67 |
| Q3 | 58.743 | 21.151 | 53.91 | 16.1325 | 15.408 | 15.91 | 11.917 | 13 | 12.25 | 3.6 | 6.608 | 3.6 |
| Maximum | 87.194 | 21.151 | 87.19 | 31.872 | 28.8 | 31.87 | 22.68 | 18.72 | 22.68 | 7.62 | 8.96 | 7.62 |
| IR | 49.719 | 18.911 | 46.506 | 11.32125 | 11.935 | 11.365 | 9.28076 | 10.12 | 9.37 | 2.7 | 6.083 | 2.736 |

Figure 3. Box and Whisker Plot for Gross Size of Project




| | Special Application | | Assembly | | Workforce Housing | | Dormitory | | Education | | Healthcare | | Hotel | | Multifamily | | Office | | Retail | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Permanent | Relocatable | Permanent | Relocatable | Permanent | Relocatable | Permanent | Relocatable | Permanent | Relocatable | Permanent | Relocatable | | Relocatable | Permanent | Relocatable | Permanent | Relocatable | Permanent | Relocatable |
| Minimum | 0.468 | 0.28 | 4.76 | 8 | 0 | 13.7 | 20.68 | 25.74 | 2.97 | 2.03 | 8.56 | 1.75 | 8.36 | 21.52 | 4.48 | 17.78 | 4.5 | 8.79 | 0.77 | 5.48 |
| Q1 | 4.88 | 4.49 | 14.5 | 16.2625 | 13.8 | 56.8 | 28.58 | 33.45 | 28.12 | 37.33 | 24.1 | 12.81 | 108.97 | 38.72 | 68.81 | 39.71 | 18.18 | 22.86 | 5.38 | 7.59 |
| Median | 13.34 | 10.9 | 33.15 | 33.9 | 101.5 | 229.15 | 107.53 | 50.76 | 47.12 | 76.27 | 46.3 | 17.45 | 141.87 | 98.78 | 160.5 | 112.54 | 30.62 | 52.68 | 12.74 | 13.89 |
| Mean | 147.86 | 138.24 | 40.1 | 289.53 | 270.9 | 449.8 | 178.6 | 162.1 | 60.63 | 154.99 | 81.8 | 80.63 | 156 | 205.5 | 224.3 | 229.75 | 52.33 | 126.43 | 22.65 | 55.33 |
| Q3 | 64.3 | 51.1 | 54.1 | 464.85 | 343 | 837.99 | 299.16 | 163.04 | 94.93 | 190.52 | 131.9 | 100 | 180.8 | 478.99 | 278.91 | 209.12 | 53.48 | 138.57 | 17.4 | 31.1 |
| Maximum | 141.67 | 77.42 | 100 | 464.85 | 408.4 | 1996.8 | 329.67 | 163.04 | 151.6 | 377.51 | 207.2 | 129.16 | 258.69 | 602.9 | 563.6 | 226.78 | 95.31 | 280 | 20.08 | 32.11 |
| IR | 59.42 | 46.61 | 39.6 | 448.5875 | 329.2 | 781.19 | 270.58 | 129.59 | 66.81 | 153.19 | 107.8 | 87.19 | 71.83 | 440.27 | 210.1 | 169.41 | 35.3 | 115.71 | 12.02 | 23.51 |

Figure 4. Box and Whisker Plot for Productivity

Figures 3 and 4 illustrate these box and whisker plots for gross size of project and productivity, respectively. The y-axis in Figure 4 represents "Productivity (sq ft/day)" while in Figure 3 it represents "Gross Size of Project (sq ft)". These plots provide a visual representation of the data distribution across different project categories.

In both figures, the boxes represent the interquartile range (IQR) containing the middle 50% of the data, with the median shown as a line within the box. The whiskers extend to the highest and lowest values within 1.5 times the IQR. Points beyond the whiskers are considered outliers. The plots reveal significant variations in both productivity and project size across different categories. These visualizations were crucial in identifying and subsequently removing major outliers, ensuring a cleaner dataset for the correlation and regression analyses conducted using SPSS software  (“IBM SPSS Statistics” 2024).

It is evident from Figure 3 that there is a major difference in the gross size of the projects between multifamily modular building type for both permanent and relocatable modular construction with the permanent modular construction having a higher median size. A similar variation was also seen in the hotel modular building type. On the other hand, Figure 4 shows the productivity between the permanent and relocatable modular buildings. In this case, it was seen that workforce housing, education and office modular buildings had a higher median productivity in relocatable compared to permanent modular buildings. While dormitory, healthcare, hotel and multifamily housing showed a higher median productivity in permanent modular buildings. Additionally, a large distribution of productivity was observed in the assembly, workforce housing and hotel modular building of relocatable modular construction.

#### 3.5.2.3 Kendall's Tau-B

In this stage, the correlation between productivity and the gross size of the project was calculated using SPSS software ("IBM SPSS Statistics" 2024). The rationale for selecting SPSS is its ability to effectively manage the intricacies of analyzing data. The software offers a wide array of statistical tests, encompassing both parametric and non-parametric tests. SPSS offers a wide range of statistical tests; however, the choice of test depends on the normality of the data. The choice between parametric and non-parametric tests depends on various assumptions, including the normality of the data, the homogeneity of variances, and the linearity of the data. If the assumptions were satisfied, the parametric tests to be done would include t-tests and ANOVA. However, if the conditions required for the tests are not met, non-parametric tests such as the Mann-Whitney U test or the Kruskal-Wallis's test must be performed (Laerd 2016). Various techniques can be employed to examine the normalcy of data, including numerical methods, graphical methods, and the use of SPSS. This study assessed the normalcy assumption using the SPSS software. In this work, the Shapiro-Wilk test was employed to assess normality using SPSS.

Each group of the independent variables underwent the Shapiro-Wilk test. The "Sig." column, which displays the significance level for each group of the independent variable under investigation, sits below the Shapiro-Wilk column. If the assumption of normality is broken in the following test, the "Sig." value will be less than 0.05, indicating that the test is statistically significant at the $p < 0.05$ level. If the assumption of normality remains intact, the "Sig." value will exceed 0.05 ($p > 0.05$). The Shapiro-Wilk test examines the null hypothesis that the data distribution is identical to that of a normal distribution. Rejecting the null hypothesis indicates that the distribution of your data is not normal. In the data examined, the significance level was less than 0.05. Therefore, the dependent variable follows a normal distribution based on the independent variable. Additionally, the normality of additional variables was also assessed.

A normality test revealed that the data did not follow a normal distribution. Therefore, it is necessary to perform a non-parametric statistical analysis. A number of non-parametric tests can be used, such as Kendall's tau-b (ϱb) test for figuring out the strength and direction of an association between two variables measured on at least an ordinal scale, the Spearman's rank test, and the Mann-Whitney U test for comparing two independent groups (Laerd 2016). The study employed Kendall's tau-b (τb) test to evaluate the variables gross size of project and the productivity. Kendall's tau-b (τb) is regarded as a substitute for the nonparametric Spearman's correlation. Spearman's correlation relies on the measurement of the two variables on a continuous or ordinal scale. Furthermore, it is essential that the two variables accurately reflect the corresponding observations. Finally, it is necessary for there to be a consistent and unchanging link between the two variables. The reason for not selecting Spearman's correlation is that one of the assumptions of the test, specifically the third assumption, was not met in this circumstance. After creating a scatterplot and visually examining the graph, it became difficult to discern the correlation between the variable productivity and the gross size of the project under investigation. Therefore, Kendall's tau-b (τb) test, which is an alternative test for Spearman's correlation, was employed. Kendall's tau-b is a statistical metric that evaluates the relationship between ordinal variables by considering the number of concordant and discordant pairings. The assessment measures the extent of a monotonic relationship and is applicable in cases where there are ties in the data (Siegel and Castellan Jr. 1988).

Prior to conducting Kendall's tau-b (τb) test on the data, an assessment was made to determine if the data satisfied the three assumptions of the test. The initial assumption is that the two variables under investigation must be assessed on a continuous and/or ordinal scale (Laerd 2016). Additionally, it is necessary for the two variables to reflect paired observations (Laerd 2016). Finally, Kendall's tau-b assesses if there is a monotonic relationship between the two variables. While it is preferable for the data to exhibit a monotonic relationship, it is not an absolute requirement (Laerd Statistics 2016). Prior to beginning the data analysis to determine the statistical significance of the correlation coefficient, it is critical to define the null and alternative hypotheses. The null hypothesis for the provided data is as follows:

H0: The two variables exhibit no relationship or correlation.

The alternative hypothesis can be stated as follows:

HA: There exists a correlation (i.e., a consistent relationship) between the variables in the population.

The findings were examined based on the given hypothesis. The outcomes of Kendall's tau-b test yield a correlation coefficient ($\tau b$) and a corresponding p-value for every pair of the variables under investigation. Kendall's tau-b is a statistical measure that can vary from +1 to -1, representing a perfect positive correlation (+1) and a perfect negative correlation (-1), respectively (Laerd Statistics 2016). Conversely, Kendall's tau-b value of zero (0) signifies the absence of a monotonic relationship between the variables. However, unlike Pearson's correlation, there are no explicit criteria to assess the strength of the link for various values. Therefore, it is understood that when Kendall's tau-b is closer to zero, the link is less, and when Kendall's tau-b is closer to +1 or -1, the association is stronger (Laerd Statistics 2016). The second stage of interpreting the results involves evaluating the p-value to determine the significance of the correlation. This determines whether to accept or reject the null hypothesis. The results of the Kendall tau-b correlation explain the relationship between the two variables in the sample but not in the entire population (Laerd Statistics 2016). Therefore, to evaluate Kendall's tau-b hypothesis, it is critical to ascertain its statistical significance. If you set $\alpha = 0.05$ (i.e., $p < .05$) and get a statistically significant Kendall's tau-b, it means that there is a less than 5% chance that the strength of the relationship you saw (your correlation coefficient) happened by chance, assuming the null hypothesis is correct (Laerd Statistics 2016) A high p-value suggests that the observed link is unlikely to be the result of random chance. The p-value for Kendall's tau-b can be in the "Sig. (2-tailed)" row of the correlation table, as depicted below. Kendall's tau-b was used to examine the link between productivity and the gross size of projects in both permanent and relocatable modular construction, within each category.

### 3.5.2.4 Linear Regression Analysis

A basic linear regression analysis examines the linear correlation between two continuous variables to predict the value of a dependent variable based on the value of an independent variable (Laerd Statistics 2016). Linear regression allows you to: (a) assess the statistical significance of the linear relationship between two variables; (b) quantify the proportion of variation in the dependent variable that can be explained by the independent variable; (c) comprehend the direction and strength of the relationship; and (d) make predictions of the dependent variable using different values of the independent variable. (Laerd Statistics 2016). In this study, the two continuous variables are productivity and the gross size of the project.

Prior to doing linear regression analysis, it is crucial to verify whether the data under examination is suitable for this specific test. Prior to evaluating the Modular Building Institute database, it is essential to consider the seven assumptions of linear regression. The first two assumptions are that the dependent variable and the independent variable are both continuous. The remaining five assumptions pertain to the characteristics of the data and can be evaluated using the SPSS statistical software. These assumptions are as follows: (a) a linear relationship exists between the two variables; (b) the observations are independent; (c) homoscedasticity is present; (d) there are no significant outliers; and (e) the residuals (errors) of the regression line follow an approximately normal distribution. The five assumptions will be elaborated upon in the subsequent paragraphs.

a) There needs to be a linear relationship between the dependent and independent variables (Laerd 2016). The dependent variable, productivity, should have a linear relationship with the independent variable, the gross size of the project. A scatterplot was constructed to assess the presence of a linear correlation between productivity and the gross size of the project. We created distinct scatter plots for each category, such as multifamily housing, to represent the permanent and relocatable modular construction

b) There is independence of observations: The Durbin-Watson statistics can verify the independence of the observations. Another crucial assumption of linear regression is that the mistakes or residuals must be independent. Independence of residuals refers to the property that each residual does not contain any information that may be used to predict or explain any other residual (Laerd Statistics 2016). The Durbin-Watson test is used to assess the independence of observations. The Durbin-Watson test is used to assess the presence of first-order autocorrelation, which indicates a lack of independence between neighboring data, specifically their mistakes (Laerd Statistics 2016). The SPSS statistics output includes the Durbin- Watson statistic, which is shown in a table called the Model Summary. The Durbin-Watson statistic for the education category for the permanent modular construction is shown below. The Durbin-Watson statistic's range is between 0 and 4. The resultant value should be close to 2, indicating that there is no correlation between residuals. According to the table, the value is close to 2, indicating the absence of error independence (residuals).

c) The data must exhibit homoscedasticity: The assumption of homoscedasticity implies that the variability of the errors (residuals) remains constant across all levels of the independent variable (Laerd Statistics 2016). The assumption of equal error variances can be assessed by examining a plot of the unstandardized or standardized residuals against the anticipated (or fitted) values or standardized predicted values, where the residuals serve as the errors (Kutner et al. 2004; Smith and R. Draper 1998). If homoscedasticity is present, the residuals (prediction errors) will be uniform across the standardized predicted (fitted) values. This implies that the data points in the plot will show no discernible pattern and will be evenly distributed around the predicted values. If the residuals are not uniformly distributed and instead exhibit varying heights, such as a funnel shape, then homoscedasticity is not present. Instead, you are experiencing a phenomenon known as heteroscedasticity (Laerd Statistics 2016).

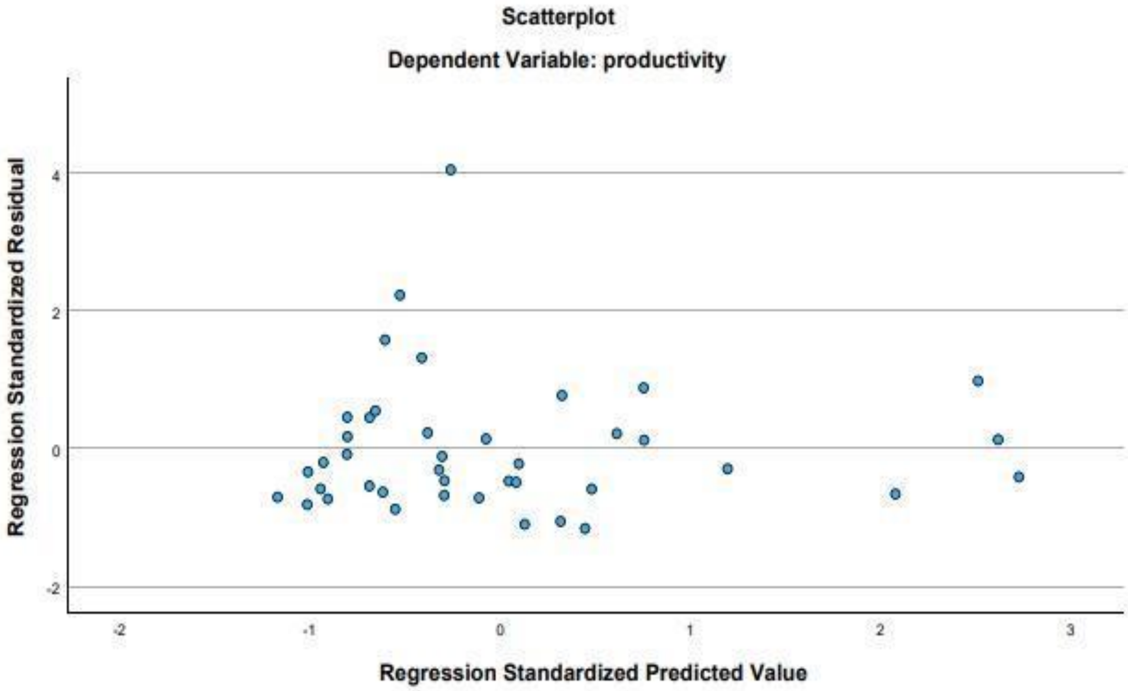



Figure 5. Plot of Standardized Residual Against the Standardized Predicted Value for Permanent-Education Category.

d) There is no significant outlier present: Outliers refer to circumstances in which the observed value of the dependent variable deviates significantly from its anticipated value (Laerd, 2016). An outlier can have a big effect on many things, such as (a) making the regression equation and statistical conclusions less accurate; (b) making the residuals much less homoscedastic; and (c) having a big effect on the regression line. Hence, it is crucial to eliminate significant outliers. The procedure for removing outliers is like the one explained in the "Cleaning of Data for Outliers section". Box and whisker plots have been generated to compare the productivity and gross size of both permanent and relocatable modular buildings in this study. The prominent anomalies detected in the box and whisker plot have been eliminated to conduct the regression analysis, resulting in the absence of any noteworthy outliers that could hinder the assumption necessary for the regression analysis.

e) The residuals (errors) of the regression line exhibit a close approximation to a normal distribution: The final assumption that must be upheld is that the residual errors should follow a normal distribution. To determine if the residual plots have a normal distribution, we employ the normal probability plots, also known as normal P-P plots. We assume that the residuals conform to a normal distribution. If the residuals have a normal distribution, the data points will be arranged in a linear pattern along the diagonal line. Indeed, the points will never be precisely aligned along the diagonal line. Furthermore, it is sufficient for the residuals to be approximately regularly distributed, since the regression analysis is quite resilient to deviations from normality. From the normal P-P plot displayed in Figure 7, it is evident that while the points do not match completely along the diagonal line, they are sufficiently close to suggest that the residuals are approximately normally distributed. Therefore, the assumption of normality is not broken.

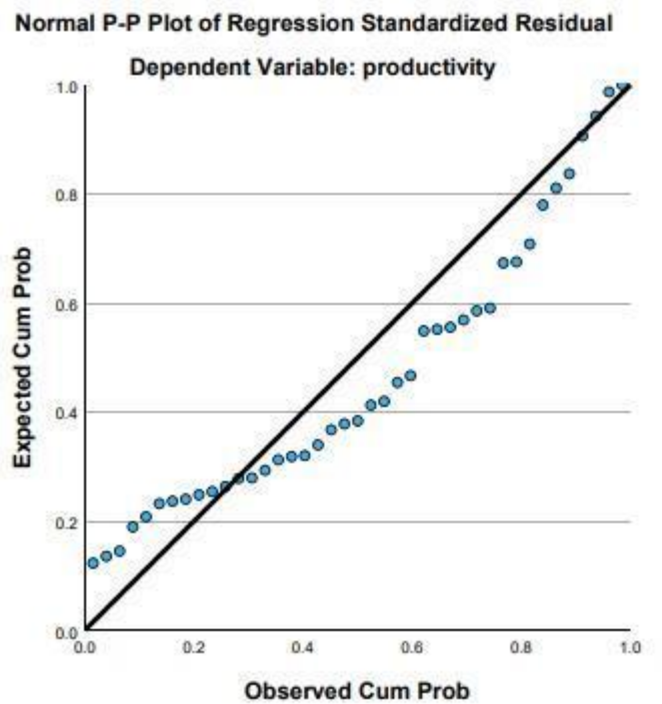



Figure 6. Normal P-P Plot of Regression Standardized Residual for Education Category of Permanent Modular Construction

## 3.6 Summary

This study employed a comprehensive methodology to analyze productivity trends in modular construction projects. The research process began with problem identification and a literature review, leading to data collection from the Modular Building Institute database. The dataset encompassed 303 permanent and 188 relocatable modular construction projects, with key variables including project characteristics, gross size, and completion duration. Productivity was calculated by dividing the total project area by the completion time. The analysis was conducted in two main parts: characteristics of modular projects (including frequency distribution, size analysis, and productivity analysis) and correlation analysis.

The correlation analysis involved distribution analysis, data cleaning to remove outliers, and statistical tests. Due to the non-normal distribution of data, as determined by the Shapiro-Wilk test, non-parametric methods were employed. Kendall's tau-b correlation analysis was used to examine relationships between productivity and project size, chosen over Spearman's correlation due to the lack of a consistent monotonic relationship between variables. Additionally, linear regression analysis was performed to further explore these relationships, with careful consideration of assumptions including linearity, independence of observations, homoscedasticity, absence of significant outliers, and normality of residuals.

This methodology allowed for a rigorous examination of productivity trends in modular construction, accounting for different project types and sizes. By combining descriptive statistics with statistical analyses, the study aimed to provide a comprehensive understanding of the relationship between project size and productivity in modular construction projects, contributing valuable insights to the field of construction management.

# Chapter 4: Results and Findings

## 4.1 Introduction

The main goal of this research was to thoroughly examine the connection between a project's size and its levels of productivity, specifically within the framework of modular construction methods. In order to accomplish this objective, a comprehensive dataset consisting of 303 permanent modular construction projects and 188 relocatable modular construction projects, covering a wide range of categories including retail, office, multifamily, healthcare, and education, was thoroughly examined. Firstly, the study was used to conduct a descriptive analysis of the dataset collected. In the descriptive analysis the characteristics of the modular projects were explored. In this case, the frequency of the modular projects, the information about the size of the modular projects and the productivity of the modular projects were analyzed. This study utilized Kendall's tau-b correlation analysis and linear regression modeling to investigate the nature and strength of the relationships between project size and productivity. The following results section provides a thorough and methodical presentation of the main findings obtained from these analyses, revealing the complex dynamics that drive productivity in modular building projects. This section seeks to provide a complete overview of the prevailing trends in the modular building sector by analyzing outcomes in numerous categories and construction modes. The goal is to enable informed decision-making and strategic planning.

## 4.2 Characteristics of Modular Projects

The following section deals with the frequency of modular projects, the descriptive analysis of the size of the modular projects and the productivity of modular projects.

### 4.2.1 Frequency of Modular Projects

The following section illustrates the frequency of modular projects in terms of the relocatability, building type, and location of the projects.

#### 4.2.1.1 Frequency of Modular Projects by Relocatability

Figure 7. illustrates the pie chart comparing the two types of modular construction according to the Modular Building Institute database. It is evident from the figure that permanent modular construction is more prevalent in the dataset accounting for 303 projects and 62 % of the total dataset. On the other hand, relocatable modular construction has about 188 projects accounting for about 38 % of the project database.

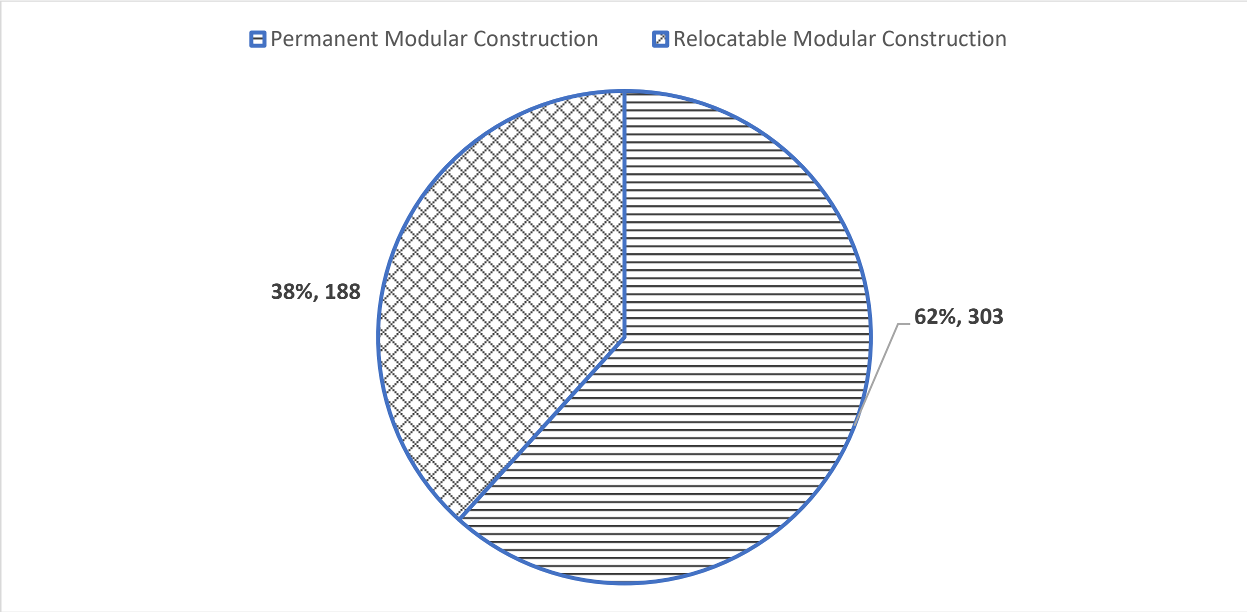
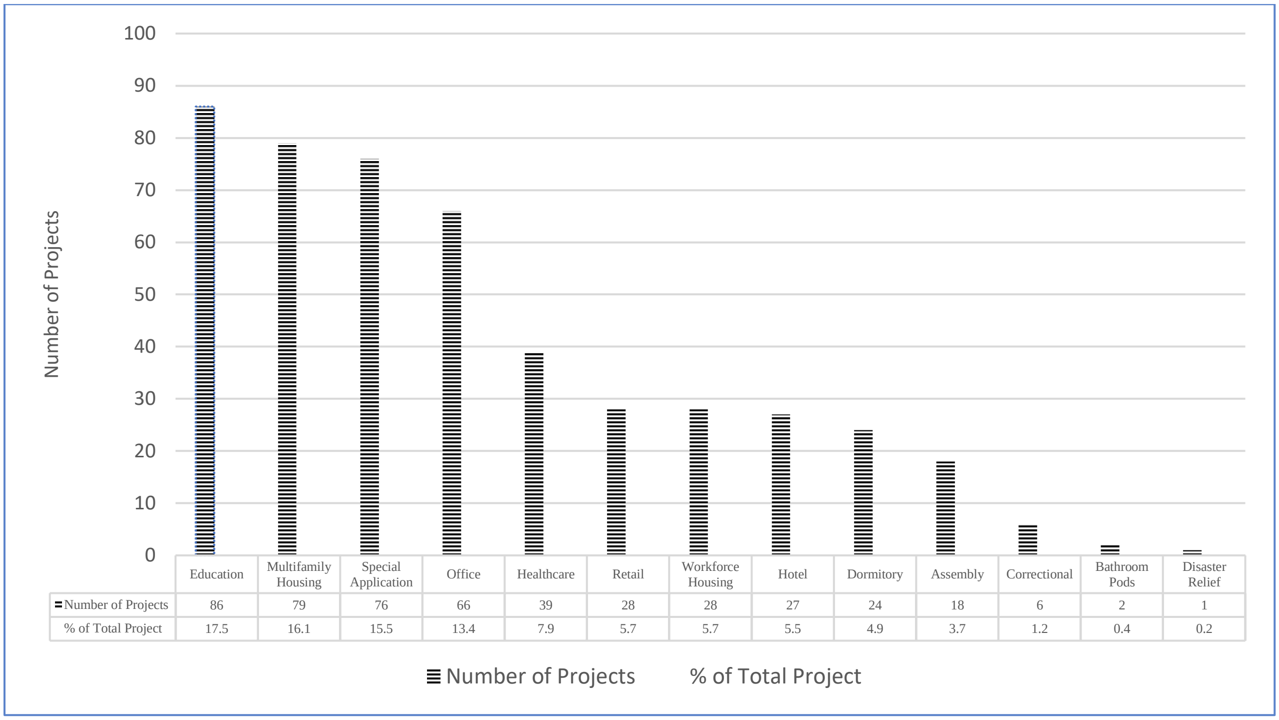



Figure 7. Pie Chart of Frequency of Modular Projects by Relocatability

**4.2.1.2 Frequency of Modular Projects by Building Type**

Figure 8. presents the data on the rankings of the different modular building types by frequency. It is evident from the following figure that education is the most common type of modular building with 88 projects representing 17.5 % of the total. Multifamily happens to be the second modular building type with 79 projects and representing 16.1 % of the total. The least common type is Disaster Relief, with only 1 project (0.2 %). The top four categories (Education, Multifamily Housing, Special Application, and Office) account for 63 % of all projects, indicating the building types where the modular construction industry is most active. On the other hand, categories like Workforce Housing, Hotels, and Dormitories each represent about 5% of projects, suggesting growing areas for modular construction.



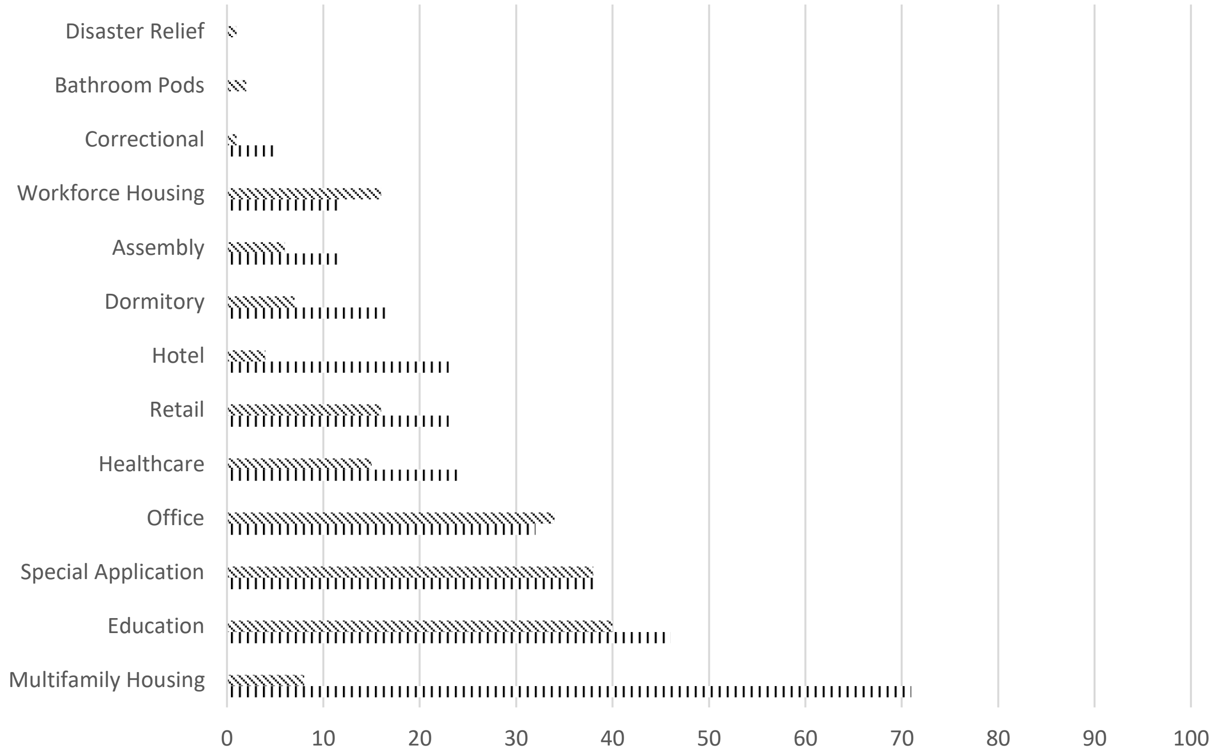

| | Education | Multifamily Housing | Special Application | Office | Healthcare | Retail | Workforce Housing | Hotel | Dormitory | Assembly | Correctional | Bathroom Pods | Disaster Relief |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of Projects | 86 | 79 | 76 | 66 | 39 | 28 | 28 | 27 | 24 | 18 | 6 | 2 | 1 |
| % of Total Project | 17.5 | 16.1 | 15.5 | 13.4 | 7.9 | 5.7 | 5.7 | 5.5 | 4.9 | 3.7 | 1.2 | 0.4 | 0.2 |

Figure 8. Frequency of Modular Projects by Building Type

### 4.2.1.3 Frequency of Modular Projects by Building Type and Relocatability

Figure 9. depicts a stacked bar chart that showcases the frequency of distinct project categories, notably distinguishing between "relocatable" and "permanent" projects. The x-axis displays many project types, including special applications, education, hotels, multifamily housing, healthcare, dormitories, correctional facilities, bathroom pods, assembly, retail, and workforce housing. The y-axis displays the quantity of projects, spanning from 0 to 80. The bar is divided into two pieces, with one section denoting the relocatable projects and the other section representing the permanent projects. The bar chart clearly shows that special application projects

are the most common, with 39 relocatable projects and 38 permanent projects. It is evident that offices, special application and workforce housing are more relocatable than permanent construction. Moreover, there is a clear pattern emerging where hotel and multifamily residential constructions are predominantly permanent, with 71 and 8 projects, respectively, as opposed to 23 and 4 projects that are relocatable. In addition, healthcare, dormitory, jail, and bathroom pods have a higher proportion of permanent projects in comparison to relocatable ones. In addition, the assembly and retail sectors have a somewhat smaller number of projects overall. More precisely, the assembly sector comprises six projects that can be relocated and twelve projects that are permanent. In contrast, the retail sector has 16 projects that can be relocated and 23 projects that are permanent. The highest percentage of permanent projects in terms of the total is seen in multifamily housing, correctional facility, hotel and dormitory.




| | Multifamily Housing | Education | Special Application | Office | Healthcare | Retail | Hotel | Dormitory | Assembly | Workforce Housing | Correctional | Bathroom Pods | Disaster Relief |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % Permanent/Total | 89.9 | 53.5 | 50 | 48.5 | 61.5 | 59 | 85.2 | 70.8 | 66.7 | 40.7 | 83.3 | 0 | 0 |
| Relocatable | 8 | 40 | 38 | 34 | 15 | 16 | 4 | 7 | 6 | 16 | 1 | 2 | 1 |
| Permanent | 71 | 46 | 38 | 32 | 24 | 23 | 23 | 17 | 12 | 12 | 5 | 0 | 0 |

Number of Projects

% Permanent/Total Relocatable Permanent

Figure 9. Frequency of Modular Projects by Building Type and Relocatability

#### 4.2.1.4 Frequency of Modular Projects by Location

Figure 10. provides valuable insights into the global distribution of modular construction projects from the modular building institute database. It is evident from the figure that North America has a strong presence of modular construction, particularly in the United States (332 projects) and

Canada (69 projects). This also shows the growing adoption of modular construction in different regions worldwide, such as Australia (22 projects), and South America (38), particularly Chile (20 projects), Argentina (10 projects), Brazil (3 projects), and Peru (4 projects), highlight the emerging modular construction market in the region. Also, European countries, such as Italy (8 projects), Spain (2 projects), Poland (2 projects), the United Kingdom (1 project), Turkey (1 project), and France (1 project), represent the diverse adoption of modular construction practices across the continent. Moreover, Asia is represented by South Korea (4 projects), China (2 projects), Hong Kong (1 project), and Saudi Arabia (1 project), indicating the presence of modular construction in various Asian markets. Furthermore, African countries, specifically South Africa (3 projects) and the Democratic Republic of the Congo (1 project), showcase the nascent but growing interest in modular construction on the continent. Lastly, the Caribbean, represented by The Bahamas (1 project) and Haiti (1 project), also contributes to the global modular construction landscape. The researcher is aware that there are more modular projects outside of MBI’s database. Many modular projects have been built in recent years in Europe and Eastern Asia, but they are not included in the database. As MBI is based in the United States, the frequency of modular projects from Northern America is overrepresented.

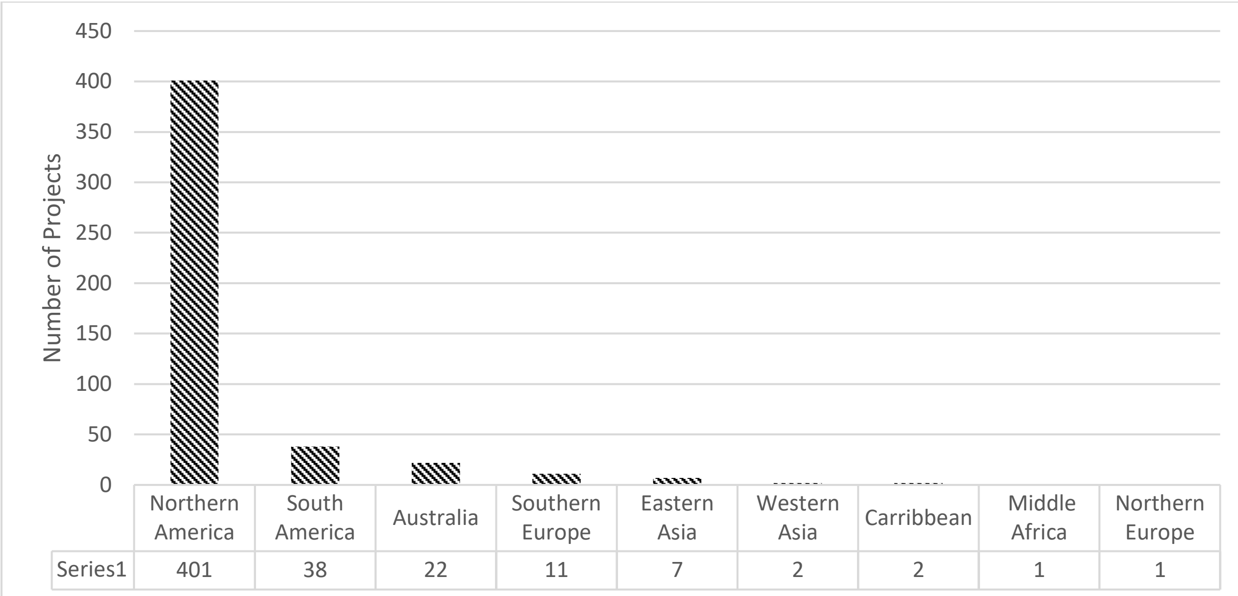



Figure 10. Frequency of Modular Projects by Location

#### 4.2.2 Size of Modular Projects

The following section tabulates the size of modular projects in terms of relocatability, building types and ranks the top 10 modular projects in terms of size.

##### 4.2.2.1 Size of Modular Projects by Relocatability

Table 1. shows the gross size of projects (ft$^2$) of two types of modular building construction. The variables which were explored happen to be the average, median, interquartile range, minimum and maximum size of the projects. It is evident from the table that there are more permanent modular construction projects compared to relocatable projects. Additionally, permanent projects

have a higher average size and median, indicating that they tend to be larger overall. Lastly, the variability in project sizes is greater for permanent projects than relocatable projects as can be seen from the higher interquartile range.

| Type of Modular Construction | Number of Projects | Median ($ft^2$) | Average ($ft^2$) | Interquartile Range ($ft^2$) | Minimum ($ft^2$) | Maximum ($ft^2$) |
|---|---|---|---|---|---|---|
| Permanent | 303 | 11916 | 41308 | 43586 | 162 | 1200000 |
| Relocatable | 188 | 4858 | 23919 | 14423 | 49 | 15861 |

Table 1. Size of Modular Projects by Relocatability

**4.2.2.2 Size of Modular Projects by Building Type**

Table 2. ranks modular building types based on the median gross size of the projects, which is measured in square feet ($ft^2$). Within the permanent modular construction category, hotel stands out as the building type with the largest median gross size, at 1672000 $ft^2$. It is followed by workforce housing and multifamily housing, which have median sizes of 48413 $ft^2$ and 43200 $ft^2$, respectively. For permanent modular construction, special application has the highest maximum value. On the other hand, in the category of relocatable modular construction, the workforce housing has the greatest median gross size at 53025 $ft^2$ and the maximum values. The

median gross sizes of relocatable building types, namely special application, bathroom pods and disaster relief. The interquartile range for each building type represents the diversity of project sizes within each category, showcasing the varying nature of modular construction projects across different applications. Also, it is seen that permanent modular building types generally have larger gross sizes compared to relocatable types. It is also seen that some building types like Bathroom Pod and Disaster Relief have no data for permanent structures but do have entries for relocatable ones.

| | Permanent | | | | | | | Relocatable | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Type of Modular Building | N | Median ($ft^2$) | Average ($ft^2$) | IQR ($ft^2$) | Min ($ft^2$) | Max ($ft^2$) | Type of Modular Building | N | Median ($ft^2$) | Mean ($ft^2$) | IQR ($ft^2$) | Min ($ft^2$) | Max ($ft^2$) |
| 1 | Hotel | 23 | 1672000 | 66678 | 42226 | 6867 | 213381 | Workforce Housing | 16 | 53025 | 126327 | 144202 | 904 | 786734 |
| 2 | Workforce Housing | 12 | 48413 | 80731 | 84924 | 3200 | 431423 | Multifamily Housing | 8 | 22763 | 65100 | 16036.3 | 3200 | 370935 |
| 3 | Multifamily Housing | 71 | 43200 | 77749 | 78840 | 525 | 501398 | Dormitory | 7 | 15000 | 17406 | 13890 | 1873 | 58600 |
| 4 | Dormitory | 17 | 16346 | 34146 | 45175 | 4032 | 139200 | Hotel | 4 | 12449 | 34082 | 29393.3 | 495 | 110934 |
| 5 | Correctional | 5 | 15252 | 36483 | 66705 | 1440 | 94648 | Education | 40 | 8996 | 17389 | 3472.5 | 59 | 149543 |
| 6 | Healthcare | 24 | 10419 | 20586 | 15456 | 1750 | 125899 | Office | 34 | 5400 | 11026.3 | 9702.8 | 896 | 73872 |
| 7 | Education | 46 | 8629 | 13915 | 10896 | 770 | 59722 | Assembly | 6 | 4860 | 15031.7 | 10034.5 | 864 | 64422 |
| 8 | Office | 32 | 6570 | 13088 | 8834 | 216 | 75000 | Correctional Facility | 1 | 4760 | 4760 | 4760 | 4760 | 4760 |
| 9 | Assembly | 12 | 4720 | 7701 | 7275 | 880 | 27504 | Healthcare | 15 | 2465 | 13892 | 4670 | 49 | 130263 |
| 10 | Special Application | 38 | 2756 | 51574 | 9178 | 162 | 1200000 | Retail | 16 | 1520 | 5420.8 | 3109 | 310 | 32000 |
| 11 | Retail | 23 | 2282 | 4149 | 2445 | 320 | 37674 | Special Application | 38 | 1167 | 6196 | 2937 | 76 | 95906 |
| 12 | Bathroom Pod | 0 | 0 | 0 | 0 | 0 | 0 | Bathroom Pod | 2 | 319.5 | 319.5 | 64.6 | 255 | 384 |
| 13 | Disaster Relief | 0 | 0 | 0 | 0 | 0 | 0 | Disaster Relief | 1 | 49 | 49 | 49 | 49 | 49 |

Table 2. Size of Modular Projects by Building Type

#### 4.2.2.3 Top 10 Modular Buildings in Terms of Size

Table 3. represents the top 10 modular construction projects ranked by their gross size, measured in square feet. The table displays the different types of modular construction (permanent and relocatable) and different modular building types. It is evident from the table that the largest project is the Cortellucci Vaughan Hospital in Canada, a permanent modular construction project in the special application category, with a gross size of 1,200,000 square feet. Additionally, the top 10 projects are in different countries, including Canada, Chile, the United Kingdom, Hong Kong, Peru, and the United States, underscoring the global nature of the modular construction industry. It is also evident from the table that the permanent modular construction projects dominated the list, with 7 out of the top 10 projects falling under this category, and the remaining 3 being relocatable modular construction projects. Moreover, multifamily housing is the most common modular building type among the top 10 projects, with 5 projects falling into this category. Lastly, the companies involved in these projects are diverse, with Tecno Fast S.A. being the only company that appears multiple times on the list (Ranks 2, 4, and 6).

| Rank | Project Name | Type of Modular Construction | Type of Modular Building | Company | Location | Gross Size of Projects ($ft^2$) |
|---|---|---|---|---|---|---|
| 1 | Cortellucci Vaughan Hospital | Permanent | Special Application | PCL Agile | Canada | 1200000 |
| 2 | COLLAHUASI – CAMPAMENTOS C20+ | Relocatable | Workforce Housing | Tecno Fast S. A | Chile | 786734 |
| 3 | College Road, Croydon | Permanent | Multifamily Housing, Green Building | MJH Structural Engineers | United Kingdom | 501398 |
| 4 | Refugio Los Bronces | Permanent | Workforce Housing | Tecno Fast S.A. | Chile | 431423 |
| 5 | United Court Transitional Housing | Relocatable | Multifamily Housing | CIMC MBS Hong Kong Limited | Hong Kong | 370935 |
| 6 | Yanacocha Project | Permanent | Special Application | Tecno Fast S. A | Peru | 364356 |
| 7 | Sterling Manor | Permanent | Multifamily Housing | Guerdon Modular Buildings | Canada | 312240 |
| 8 | Oakland International Station | Permanent | Multifamily Housing | Nashua Builders, Architects Orange & Acc U Set Construction, Inc. | United States of America | 263193 |
| 9 | 510 N Broad St | Permanent | Multifamily Housing | Volumetric Building Companies | United States of America | 256691 |
| 10 | Atlas Campaspe | Relocatable | Workforce Housing | Fleetwood Australia | Australia | 248915 |

Table 3. Top 10 Modular Buildings in Terms of Size

### 4.2.3 Productivity of Modular Projects

#### 4.2.3.1 Productivity of Modular Projects by Relocatability

Table 4. represents the productivity for two types of modular construction. The data is based on a sample of 303 permanent modular projects and 188 relocatable modular projects. The results show that the median values are similar (53.1 for Permanent, 50 for Relocatable), suggesting that the typical project size is comparable between the two types. Additionally, relocatable projects have a higher average (165.7) compared to permanent projects (129.9), indicating some larger relocatable projects are pulling up the average.  Moreover, permanent projects have a slightly larger interquartile range and a higher maximum value, suggesting more variability in project sizes. Both types have very small minimum values, with relocatable having the smallest at 0.3.

| Type of Modular Construction | Number of Projects | Median ($ft^2$/day) | Average ($ft^2$/day) | Interquartile Range ($ft^2$/day) | Minimum ($ft^2$/day) | Maximum ($ft^2$/day) |
|---|---|---|---|---|---|---|
| Permanent | 303 | 53.1 | 129.9 | 129.1 | 0.5 | 2830.2 |
| Relocatable | 188 | 50 | 165.7 | 120.8 | 0.3 | 1996.8 |

Table 4. Productivity of Modular Projects by Relocatability

### 4.2.3.2 Productivity of Modular Projects by Building Type

Table 5. presents a concise overview of the key parameters of central tendency and variability for productivity, specifically in relation to the gross size of projects each day. The data is classified into two project types: "relocatable" and "permanent.". The categories are ordered in descending order of productivity, based on the median values, for both relocatable and permanent construction. The table presents the values for the number of projects (N), median, mean, interquartile range (IQR), minimum (min) and maximum (max) for each category.

Within the context of relocatable modular construction, workforce housing exhibits the highest level of productivity, with a median value of 229.2. On the other hand, disaster relief has the lowest level of productivity, with a median value of 3.5. The presence of broad interquartile ranges indicates substantial variance within the categories.

When it comes to permanent modular construction, multifamily housing remains at the forefront, with a median of 160.5. However, the total values are often lower compared to relocatable construction. The retail sector has the lowest productivity, with an average of 12.7.

Notably, the order of categories varies between relocatable and permanent structures. There are an absence of data for bathroom pods and disaster relief for permanent category, but not for relocatable. For instance, education is ranked 4th in relocatable construction but 6th in permanent buildings.

The data shows significant variations in productivity across and within categories, as well as between relocatable and permanent construction. This variation highlights the complexity of productivity in modular construction and emphasizes the importance of doing category-specific analysis to understand and enhance performance throughout the sector.

| | Permanent | | | | | | | Relocatable | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Type of Modular Building | N | Median (ft2/day) | Mean (ft2/day) | IQR (ft2/day) | Min (ft2/day) | Max (ft2/day) | Type of Modular Building | N | Median (ft2/day) | Mean (ft2/day) | IQR (ft2/day) | Min (ft2/day) | Max (ft2/day) |
| 1 | Multifamily Housing | 71 | 161 | 224 | 206 | 5 | 1,789 | Workforce Housing | 16 | 229 | 450 | 747 | 50 | 1,997 |
| 2 | Hotel | 23 | 142 | 156 | 71 | 8 | 500 | Hotel | 4 | 128 | 116 | 75 | 23 | 184 |
| 3 | Workforce Housing | 12 | 109 | 296 | 297 | 11 | 1,740 | Multifamily Housing | 8 | 113 | 230 | 119 | 18 | 1,117 |
| 4 | Dormitory | 17 | 94 | 170 | 246 | 21 | 809 | Education | 40 | 78 | 162 | 145 | 2 | 990 |
| 5 | Healthcare | 24 | 46 | 82 | 104 | 9 | 323 | Office | 34 | 55 | 130 | 114 | 9 | 729 |
| 6 | Education | 46 | 44 | 58 | 57 | 3 | 152 | Dormitory | 7 | 51 | 162 | 88 | 26 | 715 |
| 7 | Assembly | 12 | 33 | 40 | 34 | 5 | 100 | Assembly | 6 | 34 | 290 | 69 | 8 | 1,534 |
| 8 | Office | 32 | 31 | 52 | 34 | 5 | 264 | Correctional Facility | 1 | 31 | 31 | 31 | 31 | 31 |
| 9 | Correctional | 5 | 30 | 94 | 68 | 16 | 310 | Healthcare | 15 | 18 | 81 | 75 | 2 | 442 |
| 10 | Special Application | 38 | 13 | 148 | 58 | 1 | 2,830 | Retail | 16 | 14 | 55 | 21 | 6 | 516 |
| 11 | Retail | 23 | 13 | 23 | 12 | 1 | 212 | Special Application | 38 | 12 | 142 | 45 | 0 | 834 |
| 12 | Bathroom Pod | 0 | 0 | 0 | 0 | 0 | 0 | Bathroom Pod | 2 | 11 | 11 | 1 | 11 | 12 |
| 13 | Disaster Relief | 0 | 0 | 0 | 0 | 0 | 0 | Disaster Relief | 1 | 4 | 4 | 4 | 4 | 4 |

Table 5. Productivity of Modular Projects by Building Type

#### 4.2.3.3 Top 10 Modular Buildings in Terms of Productivity

Table 6. shows the top modular buildings in terms of size according to the modular building institute database. Upon analyzing the data presented in the table, several key observations can be made. Firstly, the projects encompass a wide array of applications, including workforce housing, educational facilities, multifamily housing, and special-purpose buildings. This diversity highlights the versatility and adaptability of relocatable structures in meeting various societal needs.

Secondly, the geographic distribution of the projects and fabricators underscores the international nature of the modular construction sector. The table features projects located in Chile, the United States, Australia, Argentina, and Hong Kong, with fabricators based in these countries as well as China. This global presence suggests that modular construction has established itself as a viable construction alternative in multiple markets worldwide.

Thirdly, the productivity metrics provided for each project, measured in square feet per day, offer insights into the productivity of the modular projects. The daily output ranges from 990.4 to 2830.2 $ft^2$/day, indicating variations in the scale and complexity of the projects, as well as potential differences in the manufacturing capabilities of the fabricators.

Furthermore, the prominence of workforce housing projects in the table, particularly those associated with the mining industry in Chile, suggests that relocatable buildings are well-suited to meet the dynamic housing requirements of remote or temporary work sites. The ability to quickly deploy and relocate these structures as needed is a key advantage in such contexts. Lastly, it is evident from the table that PCL Agile happens to be the company with the highest productivity.

| Rank | Project Name | Type of Modular Construction | Type of Modular Building | Company | Location | Productivity (ft2/day) |
|---|---|---|---|---|---|---|
| 1 | Cortellucci Vaughan Hospital | Permanent | Special Application | PCL Agile | Canada | 2,830.20 |
| 2 | COLLAHUASI – CAMPAMENTOS C20+ | Relocatable | Workforce Housing | Tecno Fast S.A. | Chile | 1,996.80 |
| 3 | New Iberia Research Center | Relocatable | Special Application | BROAD U.S.A. Inc. | China | 1,788.90 |
| 4 | BROAD Garden A1 | Permanent | Multifamily Housing | BROAD U.S.A. Inc. | China | 1,788.90 |
| 5 | Refugio Los Bronces | Permanent | Workforce Housing | Tecno Fast S.A. | Chile | 1,739.60 |
| 6 | Plant shutdown-ENAP Bio Bio Refinery | Relocatable | Assembly | Tecno Fast S.A. | Chile | 1,533.90 |
| 7 | Modular Secure Storage Hawaii | Relocatable | Special Application | IteraSpace | USA | 1,280.00 |
| 8 | United Court Transitional Housing | Relocatable | Multifamily Housing | CIMC MBS Hong Kong Limited | Hong Kong | 1,117.30 |
| 9 | Atlas Campaspe | Relocatable | Workforce Housing | Fleetwood Australi | Australia | 1,028.60 |
| 10 | Pioneros Costa School | Relocatable | Education | Promet Servicios SPA | Chile | 990.4 |

Table 6. Top 10 Modular Buildings in Terms of Productivity

## 4.3 Relationship between Productivity and Size

This section describes the distribution analysis, Kendall’s Tau-B analysis and the linear regression analysis between modular projects.

### 4.3.1 Distribution Analysis of Modular Projects

There is a link between the gross size of projects (in thousands of square feet) and productivity levels (in thousands of square feet of gross projects per day) for both permanent and movable modular construction projects, as shown in Figures 11 and 12. Each data point corresponds to a distinct project, with its placement on the x-axis representing the project's size and its placement on the y-axis representing the corresponding productivity level.

The data distribution indicates a predominantly positive correlation, implying that larger initiatives often result in higher output. The positive correlation is reinforced by the upward-sloping linear regression lines that are fitted for each category. These lines show the estimated linear relationship between project size and productivity.

It is important to mention that although the general trend is good, there is significant variation in productivity levels, especially among projects of similar magnitude within the same category. The range of values shown in the scatter plot may be influenced by factors other than project size, such as project intricacy, building techniques, worker attributes, or site conditions, which are not represented in this visual representation. A statistical analysis using Kendall's tau-b and linear regression was undertaken to further evaluate the linear relationship between permanent and relocatable modular construction.

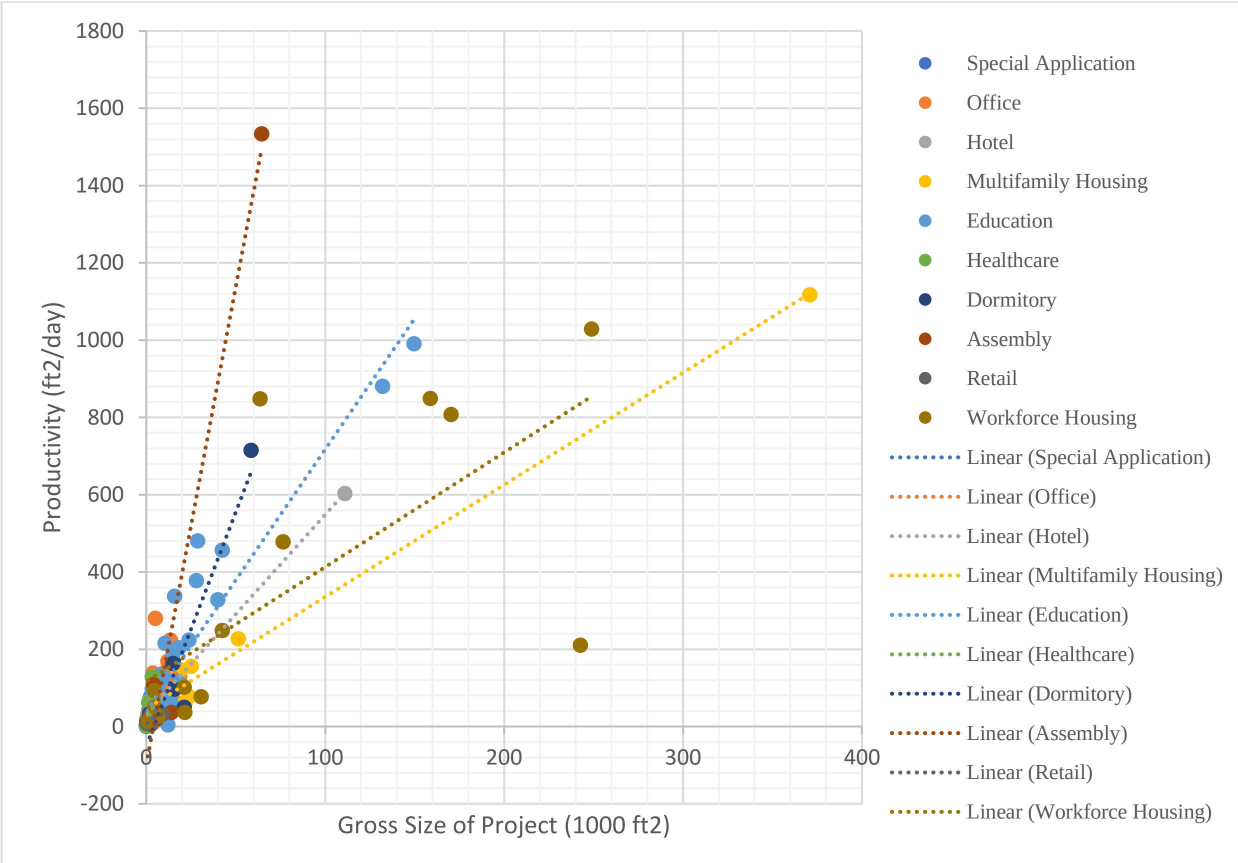


Figure 11. Scatter Plot of all the Categories of Relocatable Modular Construction

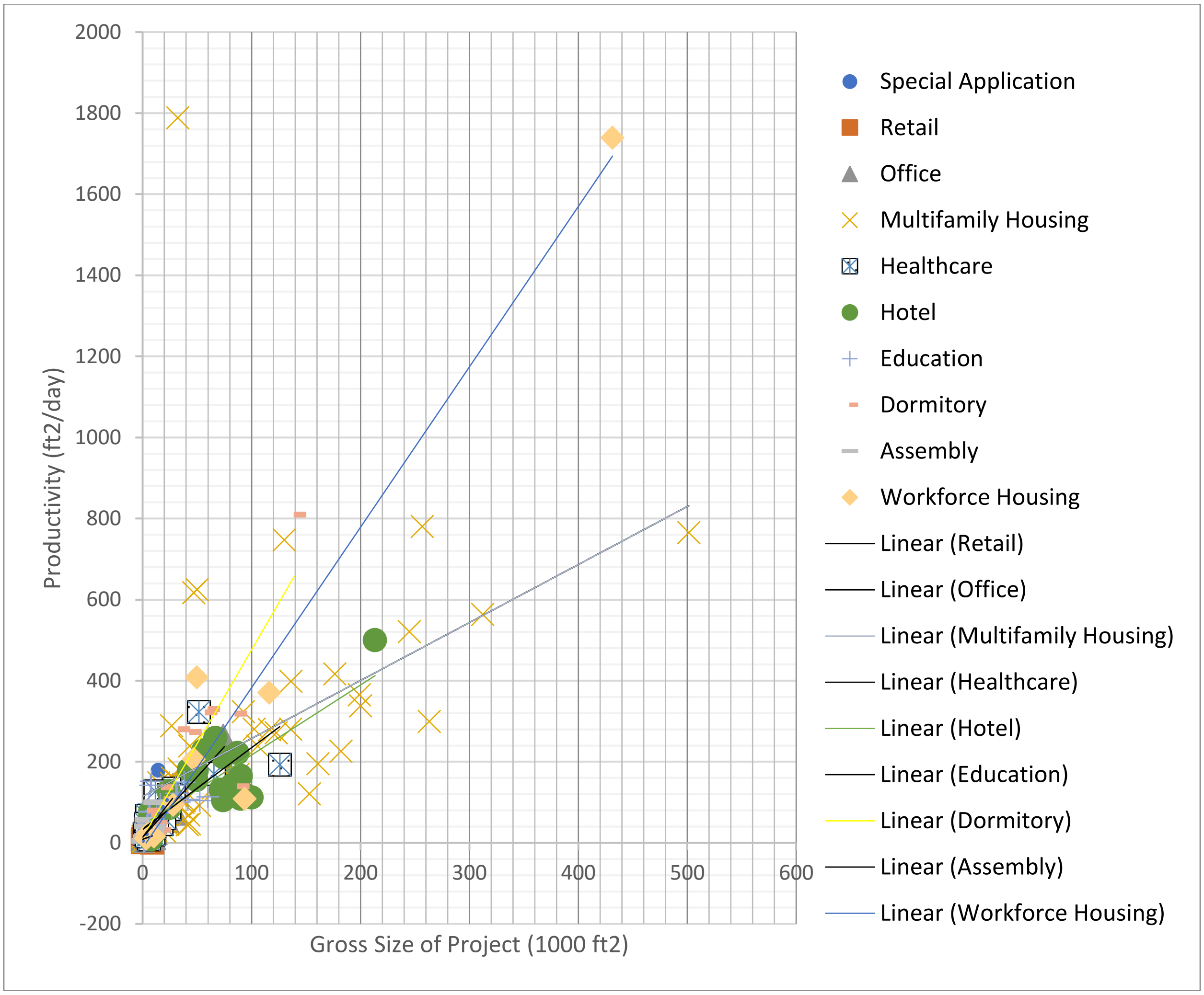



Figure 12. Scatter Plot of all the Categories of Permanent Modular Construction

### 4.3.2 Correlation Analysis

The research hypothesis states a direct association between the size of the project and the productivity of projects in both permanent and relocatable modular construction categories. Kendall's tau-b test was used to analyze the correlation between productivity (gross size of project per day) and the gross size of the project in all categories of projects in relocatable and permanent modular construction. The test was also used to evaluate the hypothesis. The examination covered a wide range of construction projects, including retail, office, multifamily, hotel, healthcare, education, dormitory, workforce housing, assembly, and special applications.

From Kendall’s tau-b analysis it is seen that workforce housing has the strongest correlation in both permanent (0.733) and relocatable (0.657), but stronger in permanent. The findings indicate a substantial and favorable relationship between the overall magnitude of the projects and their production. The p-value for this connection was less than 0.001, indicating strong statistical significance at the 0.01 level. This discovery implies that the observed correlation between the magnitude of a project and its productivity in this modular building type is unlikely to be a result of random occurrence. This corroborates the original hypothesis.

Additionally, Kendall's tau-b correlation analyses were conducted for many categories of permanent modular construction projects, including retail, office, multifamily, hotel, healthcare, education, dormitory, and assembly. In special application, the correlation is still strong in both, with slightly stronger in permanent (0.722) compared to relocatable (0.622). Education is also stronger in permanent (0.589) compared to relocatable (0.522). In comparison of permanent and relocatable modular construction Kendall's tau-b correlation analysis revealed a statistically significant positive correlation coefficient of 0.522 for permanent construction and 0.589 for relocatable modular building in the "Education" category. Moreover, retail shows a dramatic difference, with a strong correlation in permanent but weak in relocatable. Also, healthcare is on the borderline of significance for relocatable, while it's clearly significant for permanent. Several categories (Multifamily, Hotel, Dormitory, Assembly) lack data for relocatable, limiting our ability to compare across all categories.

Overall, permanent construction seems to have more categories with strong correlations, suggesting possibly more consistent relationships between variables in permanent modular construction. With the exception of the hotel category for permanent modular construction, all the other categories displayed significance in the correlation between productivity and the project's gross size. It is important to note that the hotel category had a limited dataset of only 22, which makes it difficult to establish its reliability and significance.

Similarly, the study finds strong links between the size of projects in the Office, Education, Workforce Housing, and Special Application categories and how productive they are in relocatable modular construction. However, the connections revealed in the retail and healthcare sectors did not achieve statistical significance. No reported results were found for the multifamily, hotel, dormitory, and assembly categories because of insufficient data. The retail and healthcare categories were likewise deficient in terms of a sufficient dataset.

The Appendix (Appendix A) includes the correlation coefficients, significance levels, and interpretations of the findings for these supplementary categories. Some categories had strong positive or negative correlations, while others did not demonstrate any statistically significant association between project size and productivity. The diverse results suggest that the relationship between a project's size and productivity can differ across different categories of modular construction projects.

The analysis focused solely on the association between project size and productivity, neglecting to consider any other relevant variables that could influence productivity levels. Further investigation is necessary to analyze the impact of these additional factors and evaluate the accuracy of the identified connections across different project types, geographical regions, and construction methods. To properly understand the research and its implications, it is recommended that readers refer to the comprehensive findings published in Appendix A.

| Category | Number of Datasets | Correlation Coefficient | Significance (2 Level) | Significance |
|---|---|---|---|---|
| Retail | 20 | 0.674 | <0.001 | Significant |
| Office | 27 | 0.464 | <0.001 | Significant |
| Multifamily | 64 | 0.643 | <0.001 | Significant |
| Hotel | 22 | 0.165 | 0.284 | Insignificant |
| Healthcare | 21 | 0.495 | 0.002 | Significant |
| Education | 41 | 0.522 | <0.001 | Significant |
| Dormitory | 16 | 0.661 | <0.001 | Significant |
| Workforce Housing | 10 | 0.733 | 0.003 | Significant |
| Assembly | 11 | 0.673 | 0.004 | Significant |
| Special Application | 33 | 0.722 | <0.001 | Significant |

Table 7. Summary Table for the Kendall’s Tau-b Analysis for Permanent Modular Construction

| Category | Number of Datasets | Correlation Coefficient | Significance (2 Level) | Significance |
|---|---|---|---|---|
| Retail | 13 | 0.219 | 0.299 | Insignificant |
| Office | 31 | 0.519 | <0.001 | Significant |
| Multifamily | 6 | - | - | - |
| Hotel | 4 | - | - | - |
| Healthcare | 11 | 0.455 | 0.052 | Insignificant |
| Education | 37 | 0.589 | <0.001 | Significant |
| Dormitory | 7 | - | - | - |
| Workforce Housing | 15 | 0.657 | <0.001 | Significant |
| Assembly | 6 | - | - | - |
| Special Application | 32 | 0.622 | <0.001 | Significant |

Table 8. Summary Table for the Kendall’s Tau-b Analysis for Relocatable Modular Construction

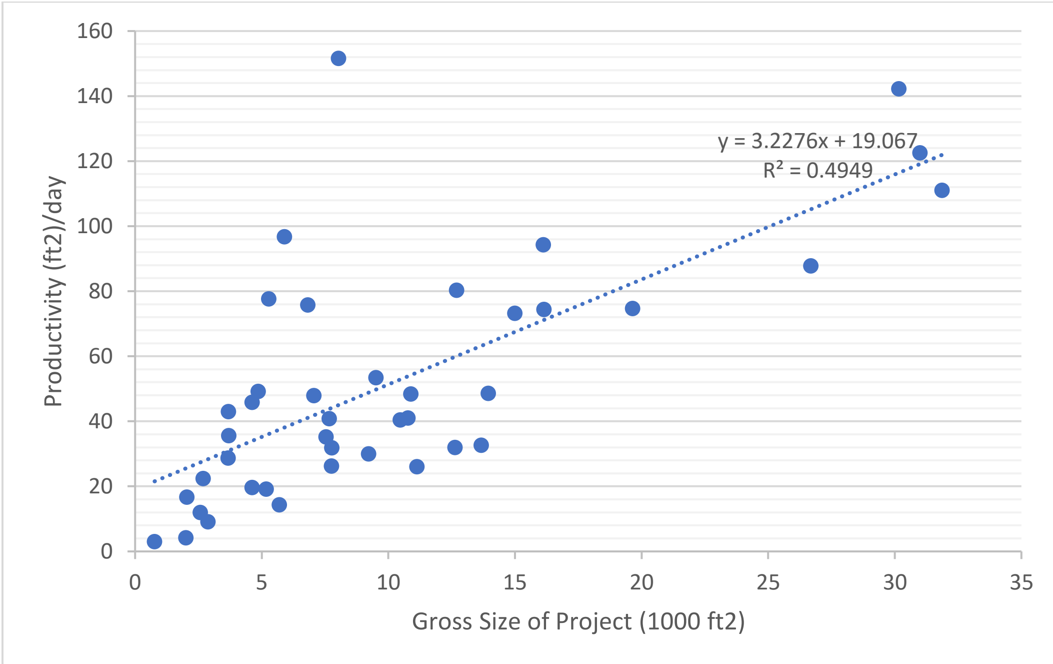



Figure 13. Education Category for Permanent Modular Construction

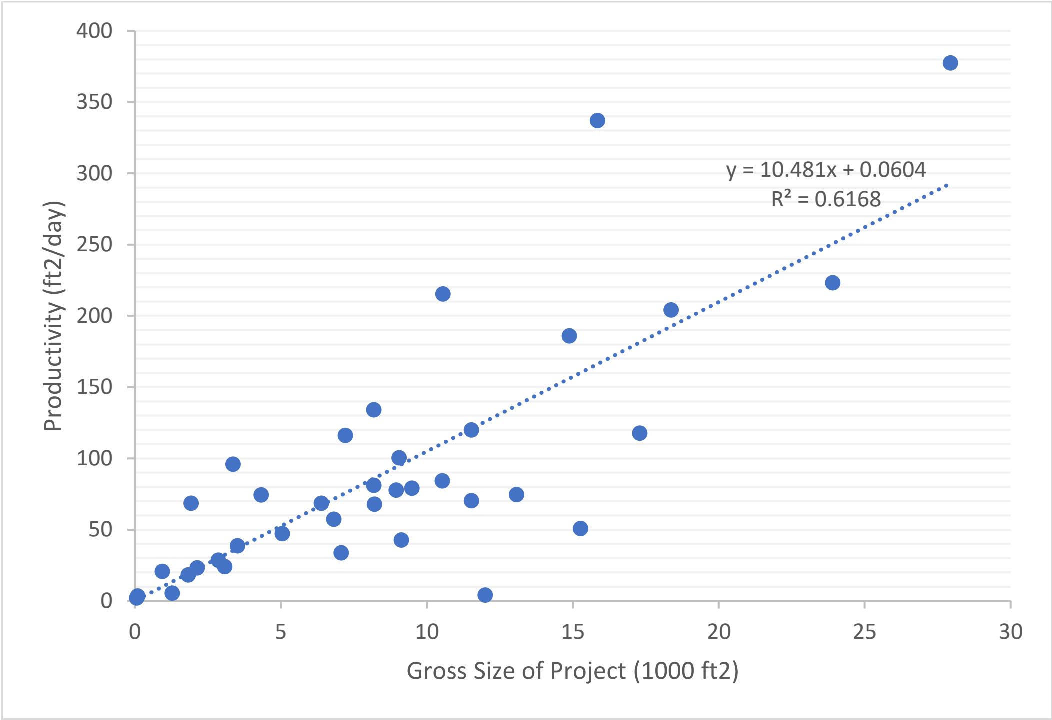



Figure 14. Education Category for Relocatable Modular Construction

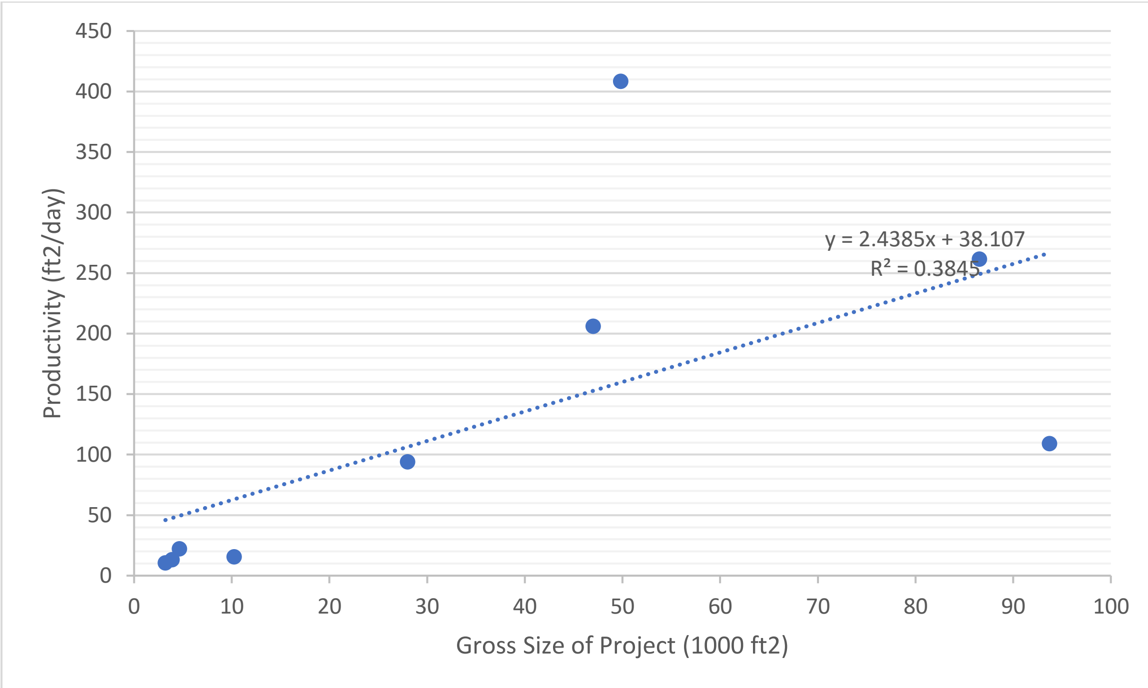



Figure 15. Workforce Housing Category for Permanent Modular Construction

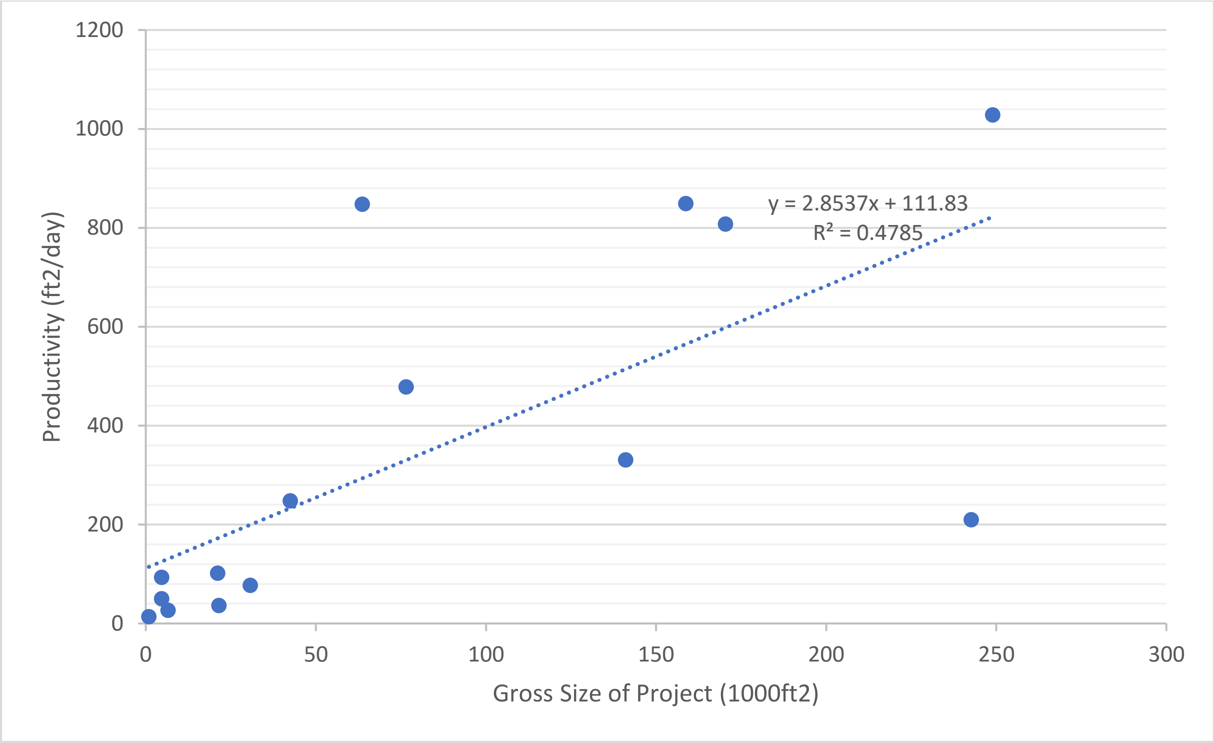



Figure 16. Workforce Housing Category for Relocatable Modular Construction

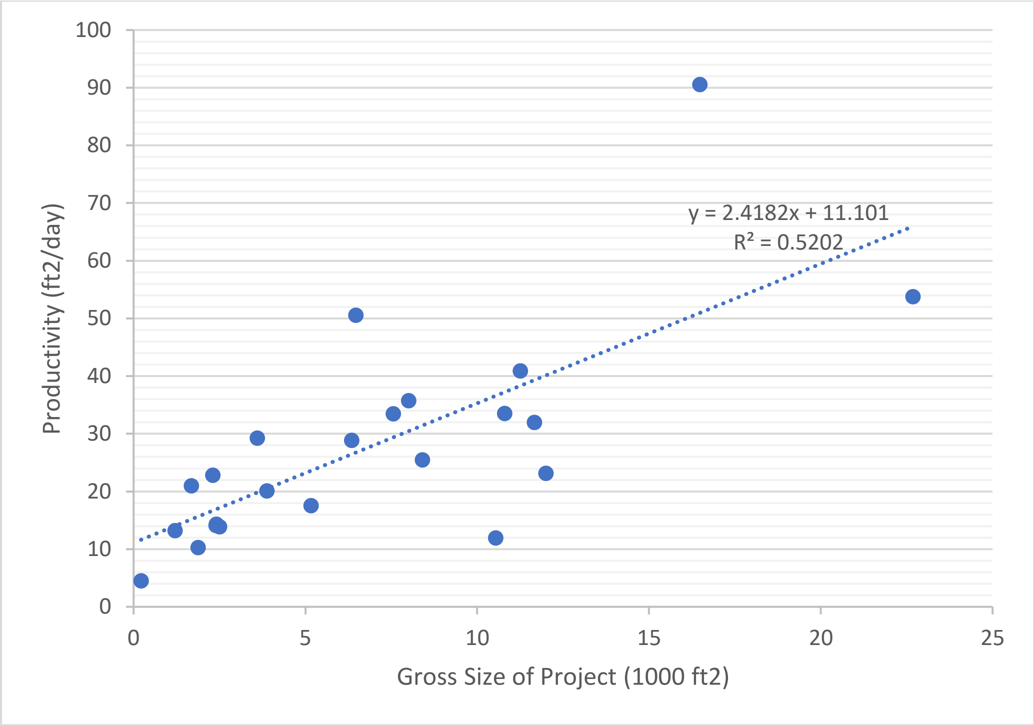



Figure 17. Office Category for Permanent Modular Construction

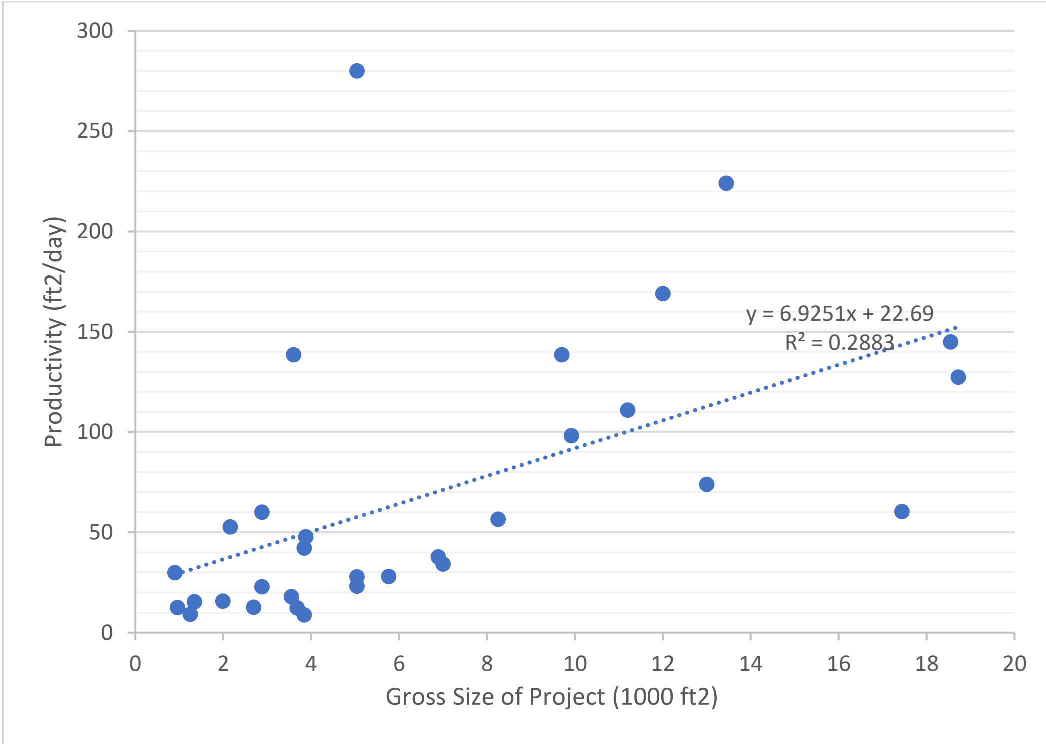



Figure 18. Office Category for Relocatable Modular Construction

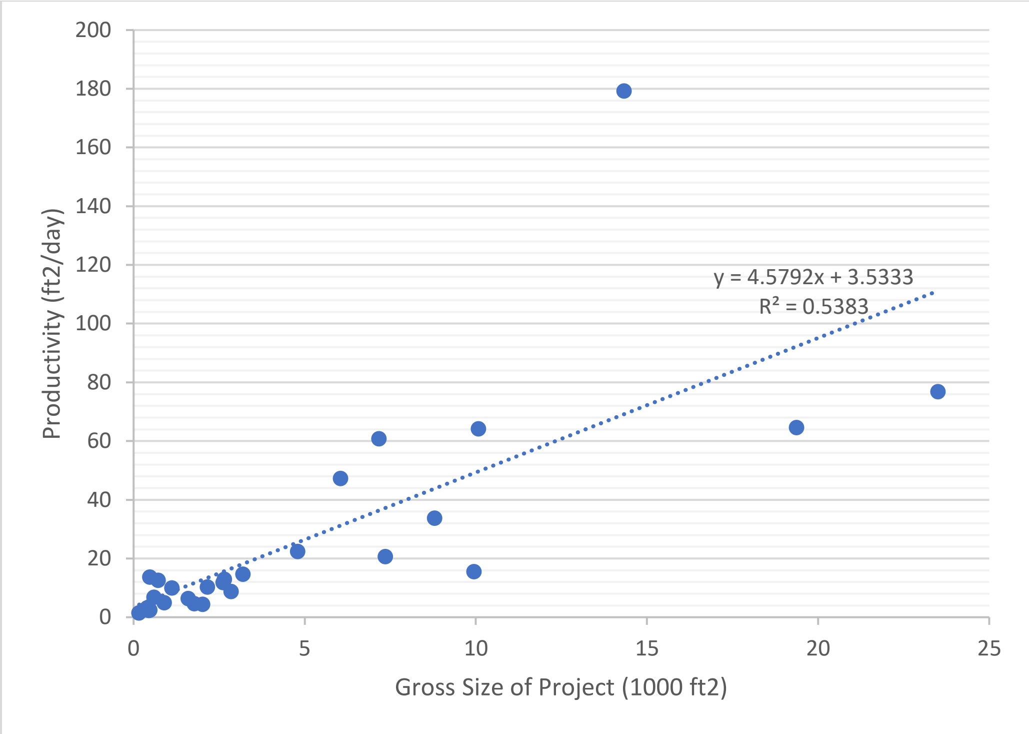



Figure 19. Special Application Category for Permanent Modular Construction

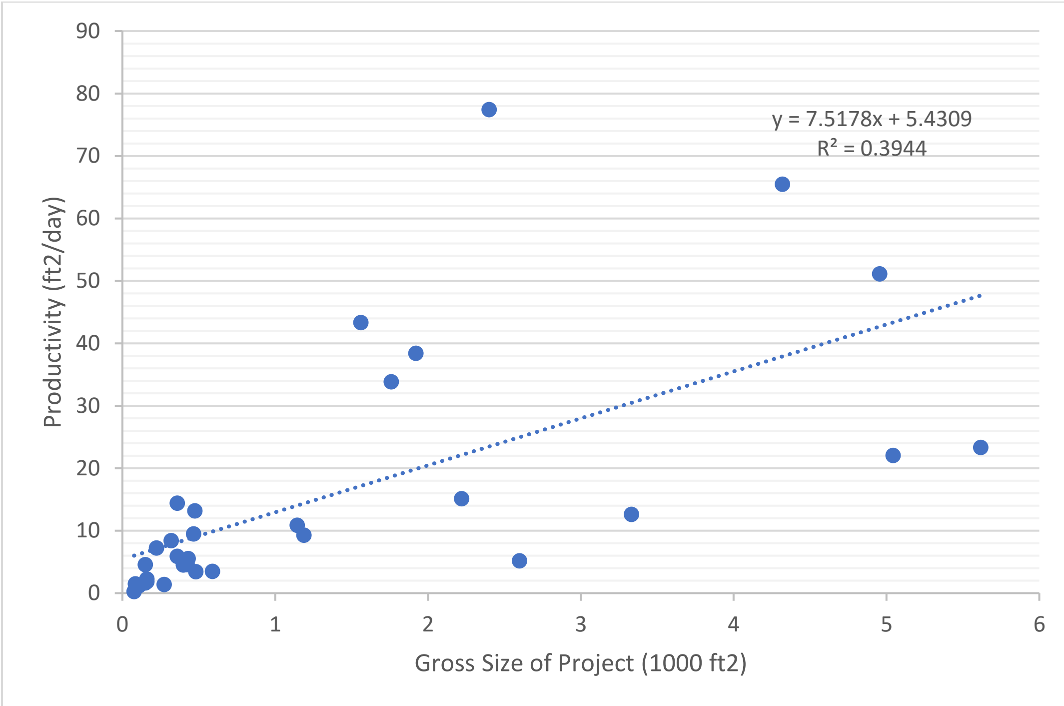



Figure 20. Special Application Category for Relocatable Modular Construction

### 4.3.3 Regression Analysis

Table 9. displays the outcomes of the linear regression analyses carried out for several categories of relocatable modular construction projects, as well as for the full dataset. Linear regression is a statistical method employed to establish a mathematical relationship between a dependent variable and one or more independent variables. In this instance, the analysis examines the correlation between the independent variable (project size) and the productivity (dependent variable).

The table presents the essential information:

1. Category: The category column provides a list of many types of relocatable modular construction and permanent modular construction projects that have been evaluated, including workforce housing, special application, retail, office, healthcare, and education. Additionally, there is a row dedicated to the complete dataset, encompassing all the data points from every category.

2. N: This column indicates the total number of observations utilized in the analysis for each category.

3. R: The multiple correlation coefficient quantifies the degree of the linear association between the dependent variable (productivity) and the independent variable(s) (project size) (Laerd 2016).

4. The R Square is a statistical measure known as the coefficient of determination. It quantifies the proportion of variability in the dependent variable that can be accounted for by the independent variable (Laerd 2016).

5. The adjusted R Square is a modified version of the R Square that takes into account both the number of predictors in the model and the size of the sample. It offers a more cautious evaluation of the model's ability to explain (Laerd 2016).

6. The standard error of the estimate refers to the standard deviation of the residuals, which are

the discrepancies between the observed values and the predicted values (Laerd 2016).

7. The Durbin-Watson statistic is employed to identify the existence of autocorrelation, also known as serial correlation, in the residuals of a regression study.

8. Significance: This column displays the p-value, which represents the statistical significance of the entire regression model. If the p-value is lower than the set significance level, such as 0.05, it indicates that the model is statistically significant.

9. Conclusion: The p-value determines whether the regression model is statistically significant or not for each category in this column.

10. Equation: This column displays the regression equation derived for each category, which may be utilized to forecast the dependent variable (productivity) depending on the independent variable (project size).

The table's findings indicate that, except for healthcare, there is a statistically significant linear correlation between project size and productivity in relocatable modular construction projects. Nevertheless, it is important to acknowledge that the healthcare sector lacks significant data. The strength of this link differs throughout categories, with education and retail exhibiting the greatest R-square values, indicating a more robust correlation between project size and productivity in these sectors.

| Category | N | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson | Significance | Result | Equation |
|---|---|---|---|---|---|---|---|---|---|
| Workforce | 15 | 0.692 | 0.478 | 0.438 | 270.3103 | 2.464 | 0.004 | Significant | 2.8537x + 111.833 |
| Special Application | 32 | 0.628 | 0.394 | 0.374 | 15.49788 | 2.363 | <0.001 | Significant | 7.518x + 5.431 |
| Retail | 13 | 0.7 | 0.49 | 0.443 | 6.20493 | 3.094 | 0.008 | Significant | 2.5483x + 9.4268 |
| Office | 31 | 0.537 | 0.288 | 0.264 | 58.23677 | 1.991 | 0.002 | Significant | 6.9251X + 22.690 |
| Healthcare | 11 | 0.383 | 0.147 | 0.052 | 36.13409 | 1.383 | 0.245 | Insignificant | 10.575X + 8.7268 |
| Education | 37 | 0.85 | 0.617 | 0.606 | 54.49797 | 1.619 | <0.001 | Significant | 10.481x + 0.0604 |
| Entire Dataset | 188 | 0.698 | 0.487 | 0.485 | 223.3887 | 2.088 | <0.001 | Significant | 0.003x + 93.711 |

Table 9. Linear Regression Summary Table for Relocatable Modular Construction

Furthermore, we employed the linear regression model to examine the permanent modular structures. Table 10. shows that the regression models are statistically significant for most categories (retail, workforce housing, special application, multifamily, hotel, healthcare, education, dormitory, and assembly), as indicated by p-values below 0.05. Nevertheless, the regression model is not statistically significant solely in the office category, suggesting that the linear model does not accurately describe the relationship between project size and productivity in this category. Furthermore, the R-square values differ throughout the categories, with the special application category exhibiting the highest value of 0.605. This suggests that the independent variable of project size accounts for about 60.5% of the variation in productivity.

Overall, the regression model is statistically significant (p-value < 0.001) when considering the full dataset. Additionally, the independent variable accounts for approximately 69.2% of the productivity variation, as indicated by the R-square value of 0.692.

| Category | N | R | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson | Significance | Result | Equation |
|---|---|---|---|---|---|---|---|---|---|
| Retail | 20 | 0.555 | 0.308 | 0.27 | 7.56844 | 2.045 | 0.011 | Significant | 0.6656x + 10.141 |
| Workforce Housing | 10 | 0.732 | 0.536 | 0.478 | 109.9278 | 2.014 | 0.016 | Significant | 2.4385x + 38.107 |
| Special Application | 33 | 0.778 | 0.605 | 0.592 | 25.88857 | 2.321 | <0.001 | Significant | 4.5792x + 3.5333 |
| Office | 27 | 0.52 | 0.271 | 0.241 | 19.04436 | 1.243 | 0.005 | Not Significant | |
| Multifamily | 64 | 0.738 | 0.545 | 0.538 | 95.35493 | 2.062 | <0.001 | Significant | 1.8036x + 55.413 |
| Hotel | 22 | 0.449 | 0.202 | 0.162 | 57.02073 | 1.846 | 0.036 | Significant | 0.9354x + 84.254 |
| Healthcare | 21 | 0.641 | 0.41 | 0.379 | 42.82063 | 1.761 | 0.002 | Significant | 3.2927x + 22.539 |
| Education | 41 | 0.704 | 0.495 | 0.482 | 26.33343 | 1.836 | <0.001 | Significant | 3.2276x + 19.067 |
| Dormitory | 16 | 0.768 | 0.589 | 0.56 | 80.96917 | 2.25 | <0.001 | Significant | 3.1955x + 48.584 |
| Assembly | 11 | 0.679 | 0.462 | 0.402 | 20.80116 | 1.635 | 0.021 | Significant | 2.4484x + 15.235 |
| Entire Data | 302 | 0.832 | 0.692 | 0.691 | 139.6135 | 1.802 | <0.001 | Significant | 4.4792x + 3.5333 |

Table 10. Linear Regression Summary Table for Permanent Modular Construction

# Chapter 5: Conclusion and Recommendation

## 5.1 Introduction

The construction sector has been experiencing a lack of progress in productivity. Additionally, there is a gap in current research regarding the relationship between project size and productivity in modular construction. To address this issue and fill the gap, this study investigated the correlation between project size and productivity in modular construction. This research contributes to the existing body of knowledge by presenting empirical data on productivity trends in different types of modular building projects.

## 5.2 Summary of What was Learned

The study revealed several key insights into the relationship between project size and productivity in modular construction. Analysis of the dataset showed a predominance of permanent projects over relocatable ones, with permanent structures generally being larger. Education emerged as the most prevalent type of modular building, while productivity varied significantly across project types. Kendall's tau-b analysis demonstrated significant positive correlations between project size and productivity for most categories in both permanent and relocatable construction, with notable exceptions in hotels for permanent structures and healthcare and retail for relocatable projects. Linear regression analysis further corroborated these findings, showing significant relationships in nearly all permanent categories except offices, and in most relocatable categories except healthcare. These results suggest that larger project sizes often correlate with higher productivity, potentially due to economies of scale and the learning curve effect, particularly in more uniform projects. This comprehensive analysis provides a nuanced understanding of productivity trends across different modular construction types and sizes, offering valuable insights for both academic research and industry practice.

## 5.3 Discussion

The main study hypothesis proposed a strong and positive relationship between project size and productivity rates in modular building projects, aligning with the concept of economies of scale. The results somewhat corroborate this idea, but with variations among project categories. For instance, the "workforce housing" category showed the highest median and mean productivity for both relocatable and permanent projects, supporting the anticipation of greater productivity in larger, more uniform projects due to the learning curve effect. However, variations in other sectors, including limited productivity in the retail industry, indicate that the relationship between project size and productivity is more complex than initially hypothesized and may be influenced by factors beyond the learning curve effect.

The findings align with previous literature emphasizing the potential advantages of modular construction, such as increased productivity and decreased building time (Azhar et al. 2013; Kamali and Hewage 2017). However, the results also highlight the challenges in consistently achieving these benefits across all project types, echoing Choi et al.'s (2016) emphasis on careful planning and risk reduction in modular construction.

The distribution analysis reveals parallels with (Bertram et al. 2019) work, indicating that the level of automation and industrialization in the industry is still relatively low. This observation aligns with the literature's emphasis on the significant investment required for manufacturing facilities and skilled professionals in modular construction (Chiang et al. 2006; Rahman 2014). The disparity between the findings and the forecasts in the McKinsey and Company report (Bertram et al. 2019) suggests that the sector has not yet fully realized its potential for improving productivity.

## 5.4 Contributions

The following section discusses the contribution the study has to the body of knowledge and to practice in detail.

### 5.4.1 Contributions to the Body of Knowledge

This study provides valuable insights into the wider field of knowledge in the area of modular building and productivity analysis. The study uses rigorous statistical approaches to perform a thorough empirical analysis. It provides quantitative evidence and insights into the complex relationship between project size and productivity levels in different categories of modular building projects. In this context, utilizing Kendall's tau-b correlation analysis and linear regression modeling approaches signifies a methodological progression, broadening the range of analytical tools available to researchers in this subject. Moreover, conducting a comparative analysis of both permanent and relocatable modular building methods allows for a more nuanced comprehension of potential similarities and differences in production patterns, enhancing the current body of literature. The findings of this study provide a strong basis for future research, encouraging greater investigation into the various elements that affect productivity. This study also sets the stage for the creation of more advanced models and analytical methods.

### 5.4.2 Contributions to Practice

The results of this study have the capacity to make a substantial impact on the modular building sector in various ways:

1. Enhanced Decision-Making: The findings can enhance decision-making processes for project planning, resource allocation, and productivity optimization techniques by offering valuable insights into the correlation between project size and productivity in different categories of modular construction.
2. Productivity Forecasting: The regression equations and models created in this study can be used by industry experts to predict productivity levels based on project size. This will allow for more precise project scheduling, budgeting, and resource management.
3. Project Selection and Prioritization: The insights obtained from this research can assist in choosing and ranking modular construction projects according to their potential for increasing productivity, especially for larger projects in categories that show strong positive correlations.

4. The study also highlights the benefits of bigger modular projects by showing a correlation between project size and productivity.

## 5.5 Recommendations for Future Research

Based on the findings and limitations of this study, the following recommendations for future research are suggested:

1. **Conduct further investigation into additional factors that affect productivity**: Although this research primarily examined the correlation between project size and productivity, future studies could delve into the influence of other factors, such as project complexity, construction methods, logistics, site conditions, and workforce characteristics, on productivity levels in modular construction projects.

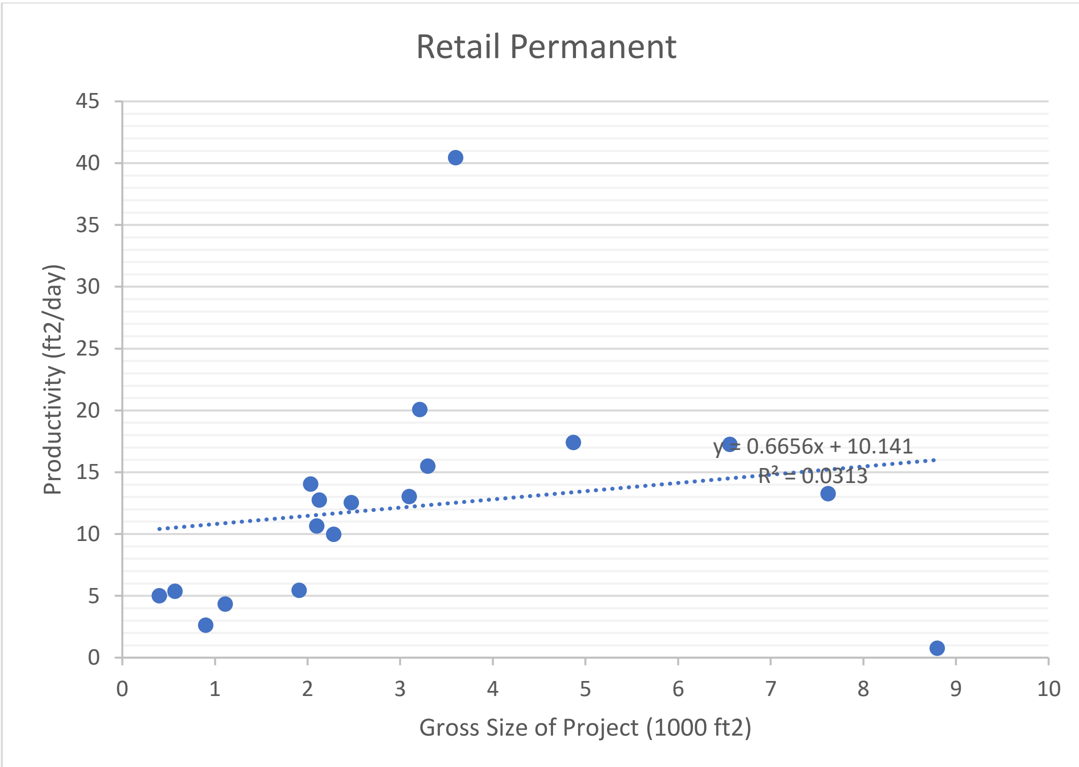
2. **Longitudinal studies and time-series analysis**: Future research could utilize longitudinal study designs and time-series analysis techniques to investigate the temporal changes in productivity levels as modular construction projects advance through various phases, including design, construction, and completion.

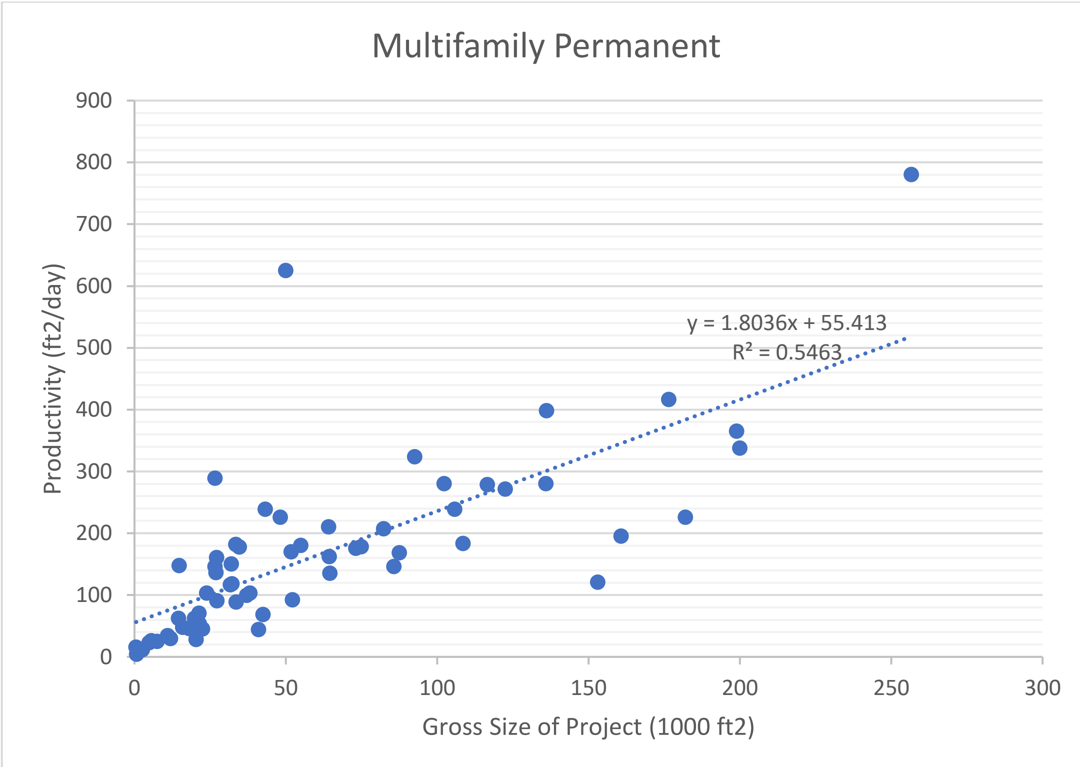
3. **Qualitative investigations**: Although this study used quantitative methods, future research could integrate qualitative approaches, such as interviews, focus groups, or case studies, to obtain more profound insights into the subjective experiences, challenges, and optimal strategies associated with productivity in modular construction projects.

4. **Investigate non-linear relationships**: The linear regression models employed in this study assumed a linear correlation between project size and productivity. Subsequent studies could

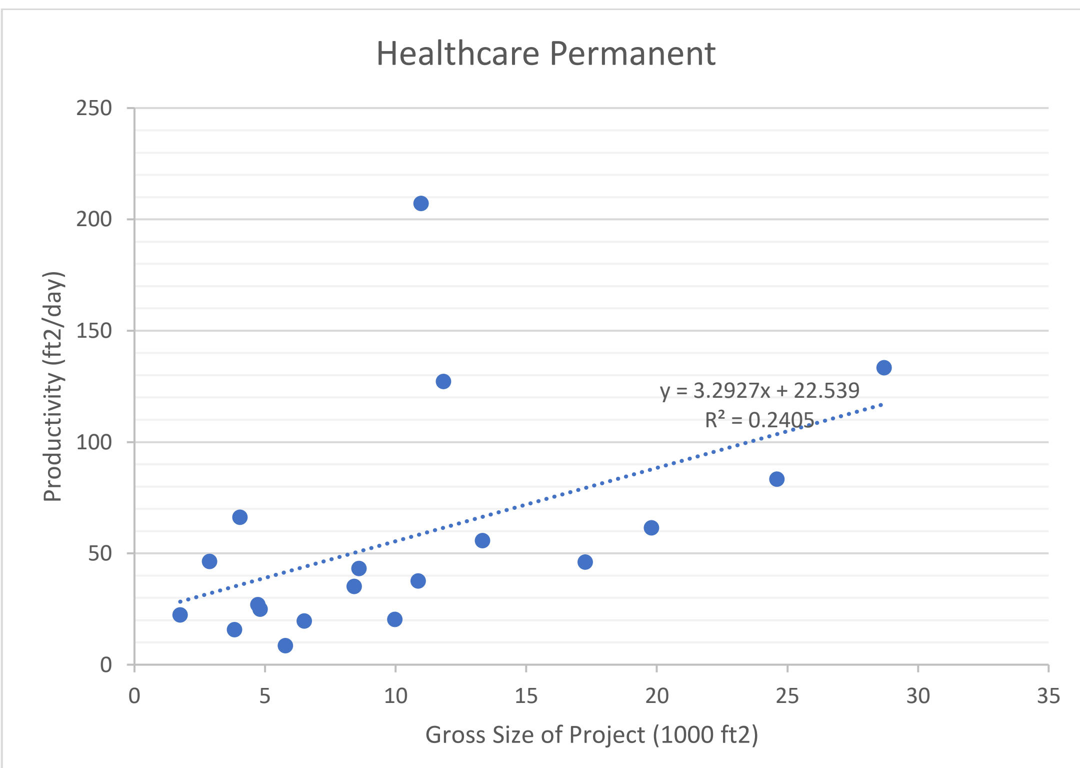
explore the possible presence of nonlinear associations or utilize more sophisticated modeling methods, such as nonlinear regression or machine learning algorithms, to capture any potential nonlinearities.

# Appendix A: Scatter Plot for Kendall's Tau-B

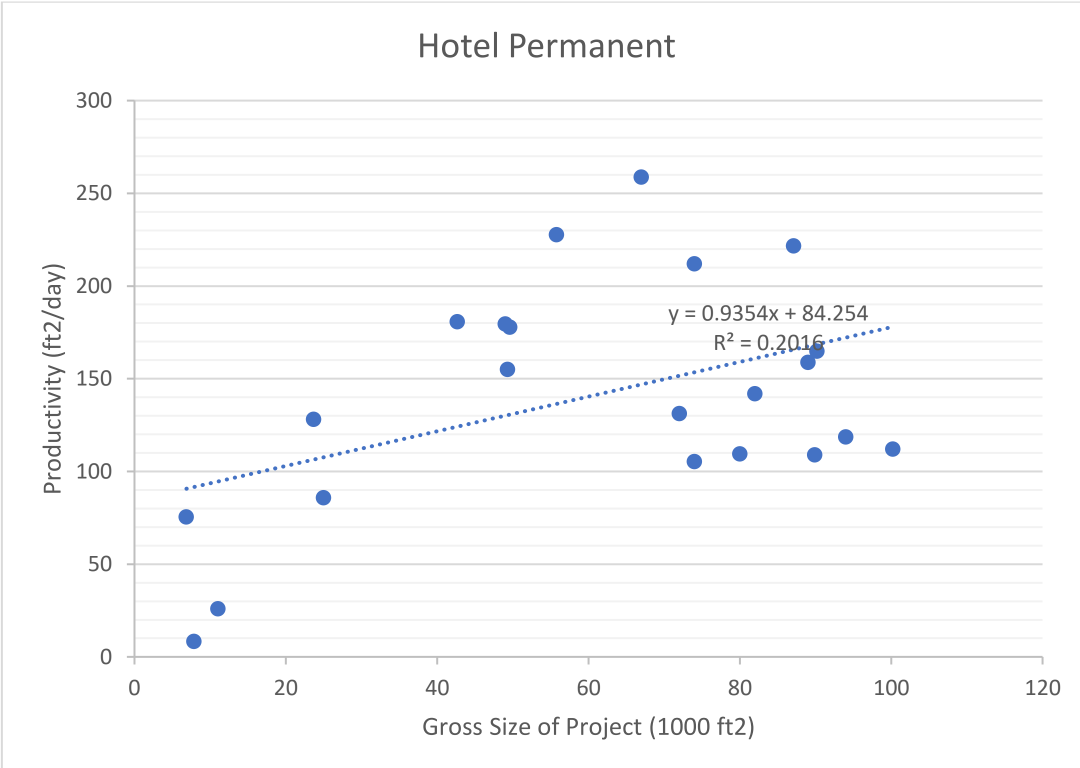


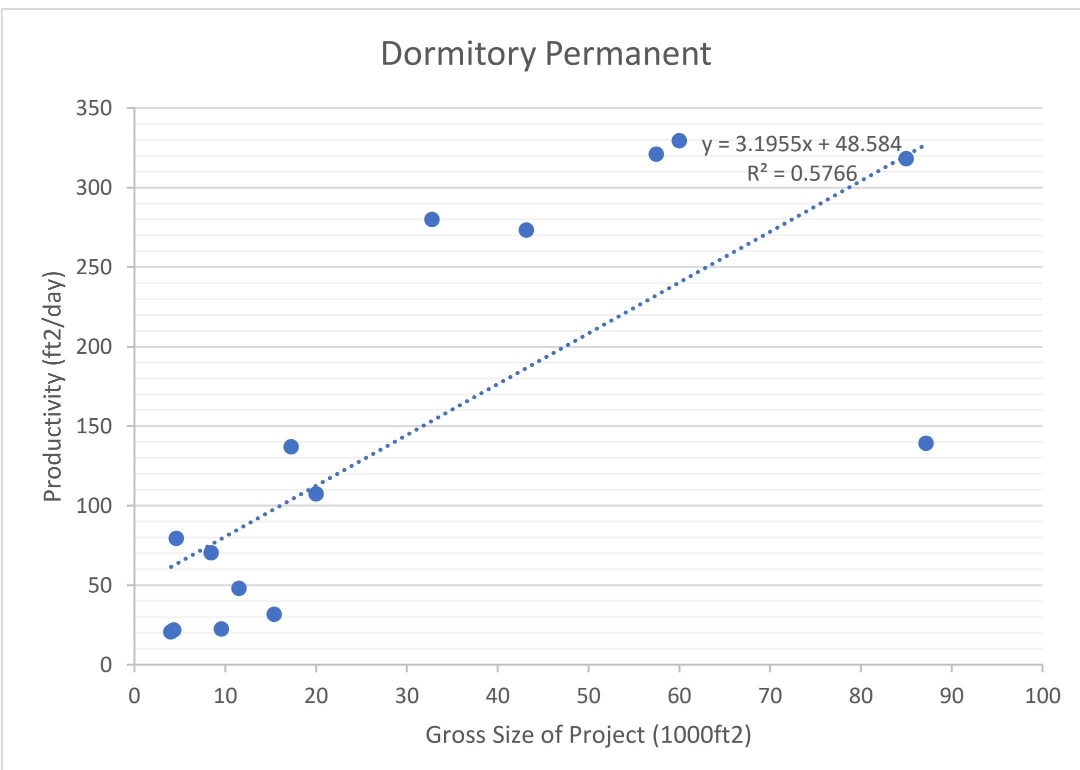


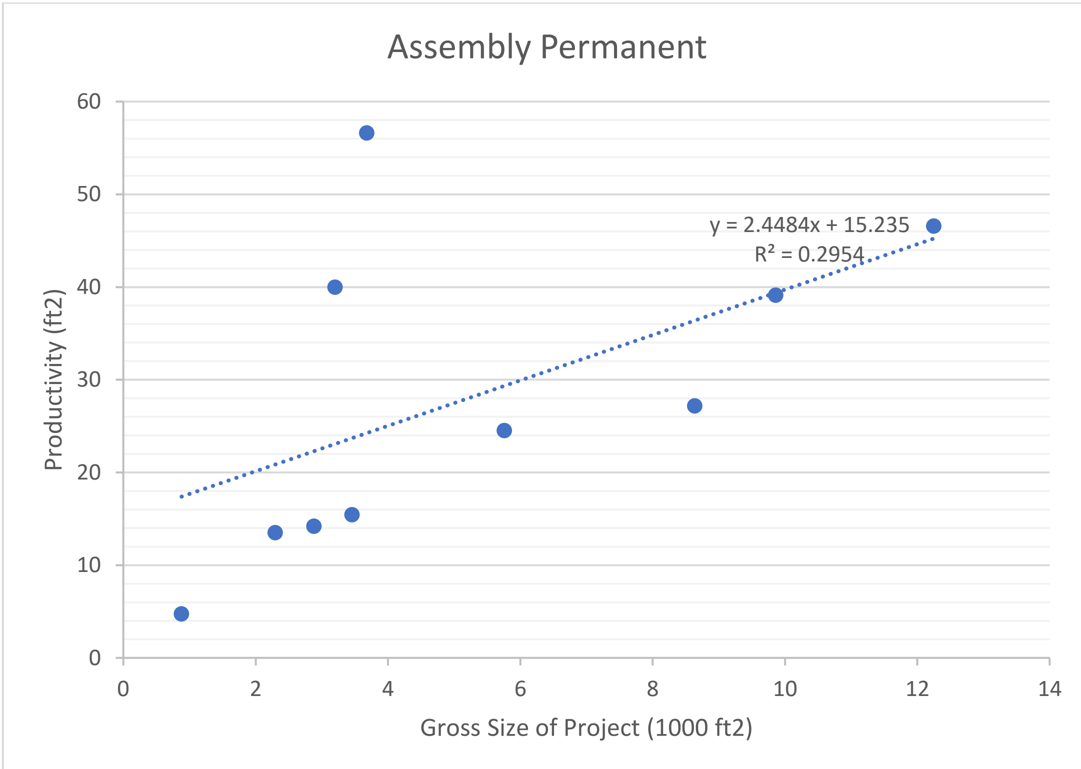
Multifamily Permanent
y = 1.8036x + 55.413
R² = 0.5463
Productivity (ft2/day)
Gross Size of Project (1000 ft2)
900
800
700
600
500
400
300
200
100
0
0
50
100
150
200
250
300

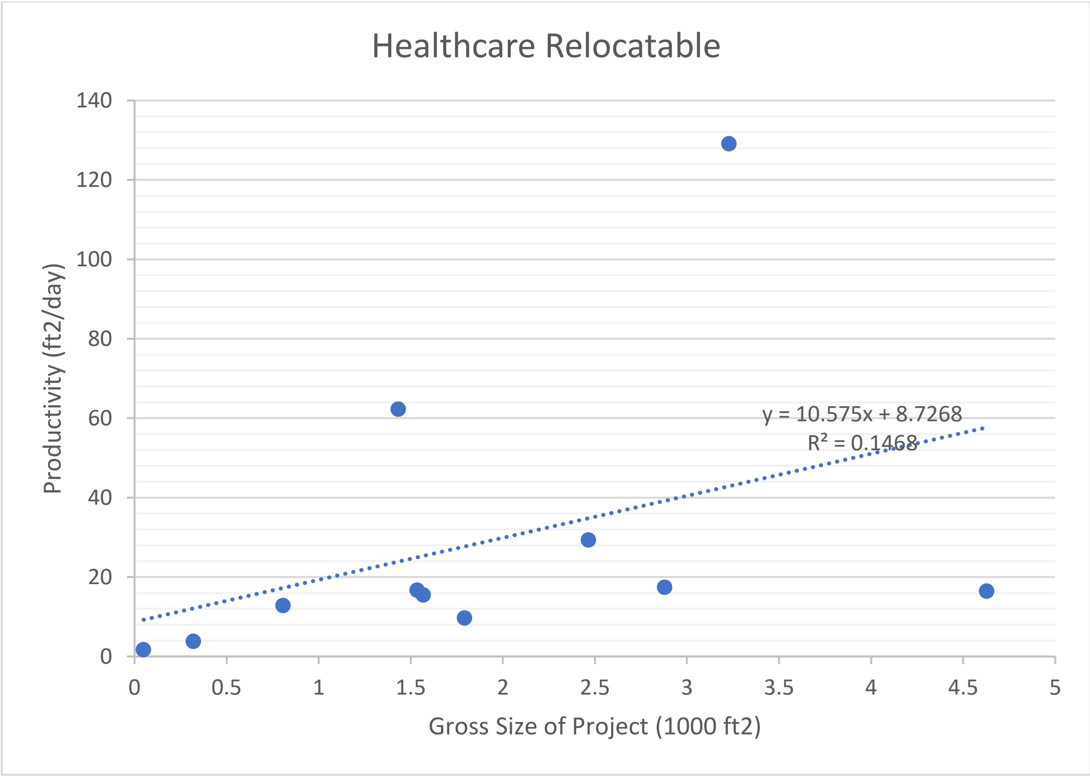



Healthcare Permanent
y = 3.2927x + 22.539
R² = 0.2405
Productivity (ft2/day)
Gross Size of Project (1000 ft2)
250
200
150
100
50
0
0
5
10
15
20
25
30
35

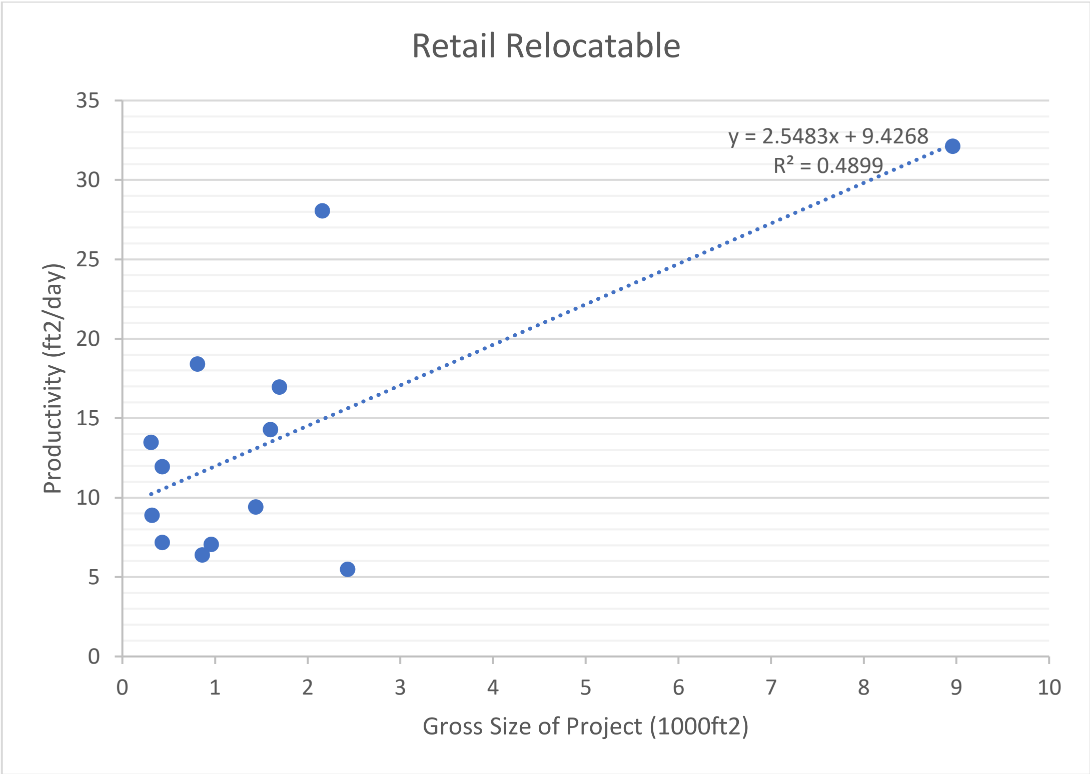

Hotel Permanent
y = 0.9354x + 84.254
R² = 0.2016
Productivity (ft2/day)
Gross Size of Project (1000 ft2)
300
250
200
150
100
50
0
0
20
40
60
80
100
120


Dormitory Permanent
y = 3.1955x + 48.584
R² = 0.5766
Productivity (ft2/day)
Gross Size of Project (1000ft2)
350
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
90
100


Assembly Permanent
y = 2.4484x + 15.235
R² = 0.2954
Productivity (ft2)
Gross Size of Project (1000 ft2)
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14



Healthcare Relocatable
Productivity (ft2/day)
140
120
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Gross Size of Project (1000 ft2)
y = 10.575x + 8.7268
R² = 0.1468


Retail Relocatable
y = 2.5483x + 9.4268
R² = 0.4899
Productivity (ft2/day)
Gross Size of Project (1000ft2)
0
5
10
15
20
25
30
35
0
1
2
3
4
5
6
7
8
9
10

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