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Benefits and Barriers of Offsite Construction in Hospital Projects

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Abstract

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Project owners of all types typically want to save time and money and increase the quality and safety of their projects. Owners continue to look towards alternate building methods to realize these benefits on their construction projects. One area that project owners continue to look at is modular construction. This study set out to understand the benefits and barriers of using modular construction on hospital projects. Despite the abundance of research related to offsite construction, there is an underwhelming amount of published literature specific to the benefits and barriers that influence hospital owners to implement modular construction on their hospital projects. Thus, this study collected data through an in-depth literature review and by conducting interviews with industry experts. This methodology resulted in obtaining data from the industry

experts about modular cost, labor, schedule, quality, safety, planning and communication, and knowledge. The number one benefit that hospital owners can achieve from using modular construction is a reduced construction schedule. Owners can achieve cost savings on projects as a result of a reduced construction schedule; however, owners are not likely to save directly on modular construction costs. Quality is incredibly important and can positively influence hospital owners to use modular construction. Safety is important but not likely a primary influencer on an owner's decision to use modular construction. Overall, the construction industry needs to work to update current building codes, which will result in more adoption of modular construction on projects. Improving education and experience could result in better modular knowledge, which would likely lead to an increased use of offsite construction.

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List of Abbreviations

3D.....	Three Dimensional
AHJ.....	Authorities Having Jurisdiction
AIA.....	American Institute of Architects
BIM.....	Building Information Modeling
BSL.....	Biosafety Laboratories
CAD.....	Computer Aided Drafting
COVID.....	Corona Virus Disease
CSF.....	Critical Success Factors
DfMA.....	Design for Manufacture and Assembly
FMI.....	Fails Management Institute
GC.....	General Contractor
HVAC.....	Heating, Ventilation, and Air Condition
ICC.....	International Code Council
IPD.....	Integrated Project Delivery
LEED.....	Leadership in Energy and Environmental Design
MBI.....	Modular Building Institute
MEP.....	Mechanical, Electrical and Plumbing
MRI.....	Magnetic Resonance Imaging
NIBS.....	National Institute of Building Sciences
OR.....	Operating Room
OSC.....	Offsite Construction
OSCC.....	Offsite Construction Council
PAV.....	Program, Aggregation, and Validation
PMC.....	Permanent Modular Construction
QC.....	Quality Control
RB.....	Relocatable Buildings
RMC.....	Regional Medical Center
WBDG.....	Whole Building Design Guide

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Chapter 1: Introduction

Project success is an important outcome for project owners on their construction projects. Inevitably, owners must make decisions that affect the successful outcome of their projects; decisions like what type of construction method is best suited for their project. Consequently, many factors such as cost, schedule, quality, safety, reduced labor, sustainability, shareholder demands, logistics, complexity, limited capital, etc., can influence the type of construction method an owner uses on a construction project.

Therefore, many owners may choose a construction method that supports a particular objective and thus they may choose an alternative construction method over a typical or traditional on-site construction method. Alternative construction methods such as offsite construction OSC, a term that often refers to prefabrication, modularization, industrialization, and other related terms, can potentially provide benefits to project owners. One particularly important and potential industry sector that stands to benefit from the use of OSC is the healthcare sector.

Many organizations tout the benefits of OSC. Organizations such as McGraw Hill Construction and Dodge Data & Analytics have conducted surveys and provided valuable information about the construction industry's use of prefabrication and modularization. In 2011, McGraw Hill conducted a survey and published a report called, "Prefabrication and Modularization: Increasing Productivity in the Construction Industry SmartMarket Report." In 2020, Dodge Data conducted a follow up survey and published a report titled, "Prefabrication and Modular Construction 2020."

These reports give valuable statistics about the application of OSC in the various industries, such as education, hospitality, and healthcare. Overall, both the 2011 and 2020 reports revealed

that construction professionals were moderately using prefabrication and modularization on healthcare projects. The 2011 report showed that the healthcare industry was using prefabrication and modularization in over 49% of its projects (McGraw Hill Construction 2011). The 2020 report showed that in the last three years, General Contractors', and Construction Managers' used prefabrication on 40% of their healthcare projects (Dodge Data & Analytics 2020). Moreover, these same contractors and managers predicted that they would use prefabrication on 49% of their healthcare projects over the next three years (Dodge Data & Analytics 2020). By these accounts, McGraw Hill and Dodge Data show that the industry professionals surveyed in the 2011 and 2020 reports are using OSC on nearly half of their healthcare projects. Consequently, these results imply that there is an advantage or benefit to using prefabrication and modularization.

The report from 2011 showed that healthcare facilities are in the best position to use prefabrication and modular construction. The report stated, "Healthcare is a sector that is well-suited for prefabrication and modularization techniques. The interior layout of hospital rooms allows for efficient use of modularization, and it is a sector highly responsive to strategies that shorten schedule – a particular benefit prefabrication brings to a project" (McGraw Hill Construction 2011). Overall, both reports spoke positively about the use of prefabrication and modularization on healthcare projects.

Bearing in mind that roughly half of all healthcare projects incorporate OSC and considering that healthcare projects are in the best position to use prefabrication and modular construction, why are more hospital owners not using OSC? Perhaps owners who use OSC recognize the value of this construction method while those who do not use this construction technique, lack knowledge related to its value. Alternately, perhaps it is contractor experience that drives the use of offsite construction or perhaps it is contractor availability. For example, some

owners may not know an experienced contractor or perhaps there are no experienced contractors in an owner's location. Azhar, Lukkad, and Ahmad (2013) state, "the decision-making process of selecting one construction method over another is complex and based on a number of factors, some of which are site conditions, skilled labor availability, transportation conditions, organizational readiness, local codes, project schedule and budget, sustainability requirements, and design complexity." An analysis of current literature about OSC could help answer this question. There is an abundance of literature about the topic of OSC, especially about the residential sector, and generally the main literature topics include: the benefits, the drivers, the critical success factors (CSF), and barriers of OSC. It is important to note, much of the current literature broadly explains and applies these factors generally to all construction sectors rather than just one specific construction sector like healthcare. For example, there is a limited amount of academic research explaining the benefits, drivers, success factors, and barriers of OSC as it pertains to just hospital projects.

Academia has not sufficiently researched why some hospital owners use volumetric building components on their hospital projects and why some do not. Therefore, this research aims to understand why some hospital owners choose volumetric OSC while others choose to use traditional onsite construction methods. To answer this question, this research will determine the benefits and barriers that influence healthcare owners to use OSC on a hospital construction project. At the outset, this research hopes to advance the body of knowledge on this topic.

The rest of this introduction will define OSC, industrialization, prefabrication, and modular construction, and identify and define the offsite industry segments. The remaining chapters will focus on the review of related literature, methodology, analysis, conclusions, provide a summary and recommendations for further research.

1.1 Defining Terms Associated with Modular Construction / Offsite Construction

The industry tends to loosely use modular construction, and vice versa, in place of prefabrication or premanufacture, and the definitions associated with the terms *prefabricated* and *premanufactured* can vary from person to person. To clear up any confusion, this study will use the terms prefabrication and premanufacture interchangeably. This study generally defines prefabrication or premanufacturing as a building component or building components assembled offsite away from the project site, and then delivered to the project site for installation. Typical components can include interior and exterior wall panels; mechanical, electrical, and plumbing (MEP) risers; hospital headwalls; bathroom pods and other prefabricated building components. Technically, *Modular construction* is a volumetric or three-dimensional enclosure that built or assembled offsite and then transported to the site for assembly, such as a bathroom pod. Despite these technicalities, during the interviews the researcher and the interviewees loosely used the term modular to mean prefabrication and vice versa. Both modular and prefabrication are terms nested within the term offsite construction. Offsite construction encompasses all aspects of prefabrication and/or modular construction from the planning phase to final installation at the jobsite.

The above-mentioned terms are typically associated with a particular process, application, or even a particular stakeholder. For example, third-party manufacturers who own manufacturing facilities (referred to as modular manufactures), or general contractors (GC) and subcontractors who rent, or purchase their own warehouse space, can all be producers of *prefabricated* or *modularized* building components. These producers typical prefabricate or modularize these building components offsite away from the project site. Though it is possible to prefabricate a building component onsite, in this study the term prefabricate is referencing a building component produced offsite. As already stated, examples of prefabricated or modularized building

components produced offsite might include bathroom pods, exterior and interior panels, MEP risers, hospital headwalls, patient room pods, laboratory pods, administrative pods, etc. For the reader, typically the construction industry breaks building components into categories such as panels, modules, cassettes, risers, etcetera.

For the remainder of this study, the reader should be aware that modular construction, modular manufacturing, offsite construction, offsite manufacturing, prefabrication, premanufacturing, peri-fabrication and near-site fabrication may all have slightly different meanings to different construction and manufacturing experts. However, this study does not intend to focus on one application, i.e., prefabrication versus modularization or bathrooms pods versus panelization. Instead, the study focuses on any *modular building component prefabricated offsite*.

Again, it is important to note that while this study may use terms such as prefabrication, modular construction, it is not the intent of the study to focus on a specific application of offsite construction. Therefore, this study may use prefabrication and/or modular construction interchangeably throughout this text; but the spirit behind these terms represents any offsite construction application.

Despite the generalization of the terms listed above, the following is how the industry defines some of those terms. How does the industry define OSC? To answer this question, we can turn to the National Institute of Building Science (NIBS). The United States Congress recognized the need to enhance the built environment and set up the NIBS in 1974. In 2013, the NIBS set up the Offsite Construction Council (OSCC). The OSCC's mission is to "serve as a research, education and outreach center to develop relevant and current information on offsite design and construction for commercial, institutional and multifamily facilities" (OSCC 2021). The OSCC uses the Whole Building Design Guide (WBDG), an online industry tool that offers up to date

information about construction and design. The WBDG defines OSC as “the planning, design, fabrication and assembly of building elements at a location other than their final installed location to support the rapid and efficient construction of a permanent structure” (OSCC 2021) An important take away from the WBDG’s definition is that OSC is a process. Offsite construction involves more than just assembling building elements offsite. It is a collaborative process that involves various stakeholders at various phases, which includes planning, designing, fabricating, and assembling.

Unfortunately, the OSC industry has some minor challenges when it comes to naming conventions. Scholarly information, organizational literature, case studies, reports, etc., commonly use the term OSC interchangeably with terms such as industrialization, prefabrication, and modularization. These terms primarily have the same meaning; apart from modularization having one fundamental difference. To understand this fundamental difference and ensure a shared understanding, sections 1.1, 1.2, and 1.3 further define industrialization, prefabrication, and modularization.

1.2 Defining Industrialization

According to the book “*Offsite Architecture: Constructing the Future*” by Ryan E. Smith and John D. Quale, industrialization or industrialized building is “any part of a building or other structure that is in whole or in substantial part fabricated in an offsite manufacturing facility for installation or assembly at the building site” (Smith 2017). Section 1.3 will show that prefabrication has a similar definition.

1.3 Defining Prefabrication

Offsite construction industry experts such as Smith and Quale define prefabrication as “a general term for the manufacture of entire buildings or parts of a building off site prior to the assembly on site” (Smith 2017). Smith and Quale noted that prefabrication is now more commonly known as OSC. Overall, surveys show that respondents are using prefabrication more often and its use on construction projects is increasing. The 2020 Dodge Data & Analytic report showed that “94% of survey respondents cite experience with prefabrication over the last three years” (Dodge Data & Analytics 2020). Furthermore, the report ranked the top ten building types in which trade contractors use prefabrication. Over a three-year prior, trade contractors claimed that healthcare facilities were the number one building type in which they used prefabrication (Dodge Data & Analytics 2020). In addition, trade contractors forecasted that healthcare facilities would remain as the number one building type over the next three years (Dodge Data & Analytics 2020).

Prefabrication involves manufacturing a product offsite; however, the responsible party can assemble the product on or off the project site. Prefabrication can include standardized or customized products. Manufacturers often mass produce prefabricated products, which makes for a responsive supply chain that results in a decreased construction schedule. Furthermore, trade workers can incorporate standardized products on a variety of projects without having to go through a lengthy design process. For example, prefabricated products could include windows, doors, or other standardized building components.

Not all manufactures limit themselves to only prefabricating standardized products; many manufactures are able to prefabricate customizable building components for a construction project. For example, manufacturers may offer prefabricated customizable bathroom pods, which are well suited for certain project types. The Modular Building Institute (MBI), a non-profit trade

association for the modular construction industry produced a white paper on the use of prefabrication and bathroom pods. The MBI claimed that, “Buildings such as hospitals, hotels and housing are ideal for the use of prefabricated building components, such as bathrooms, kitchen and headwalls” (Modular Building Institute 2017).

Lastly, Smith and Quale also say that prefabrication or OSC can include “portable buildings and various types of permanent building systems” (Smith 2017). The OSC industry two industry segments; they are portable buildings and permanent building systems. Section 1.5 will explain the industry segments in more detail. These industry segments include terms such as module, modular, volumetric, modularization and others. Section 1.4 defines modularization.

1.4 Defining Modularization

Put simply, the terms module, modular, modular system, modular construction, and modularization are associated with prefabrication. However, one fundamental difference exists between these terms and prefabrication; they specifically deal with volumetric construction. Smith and Quale defines volumetric as “volumetric building modules where the units form the structure of the building as well as enclosing useable space” (Smith 2017). Figure 1.1. provides an example where the structural units form the structure of the building.

Volumetric building modules can be either structural or non-structural. Examples of non-structural volumetric building modules might include bathrooms, shower rooms, and kitchens (Smith 2017). Volumetric building modules rarely have the same design from project to project. Figure 1.2 shows a bathroom pod (“Integrated Modular Design - Your Modular Solution Is Here” n.d.).

The Modular Building Institute (MBI), a non-profit trade association for the modular construction industry, defines modular construction as “a process in which a building is

constructed offsite, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities – but in about half the time” (MBI, n.d.).

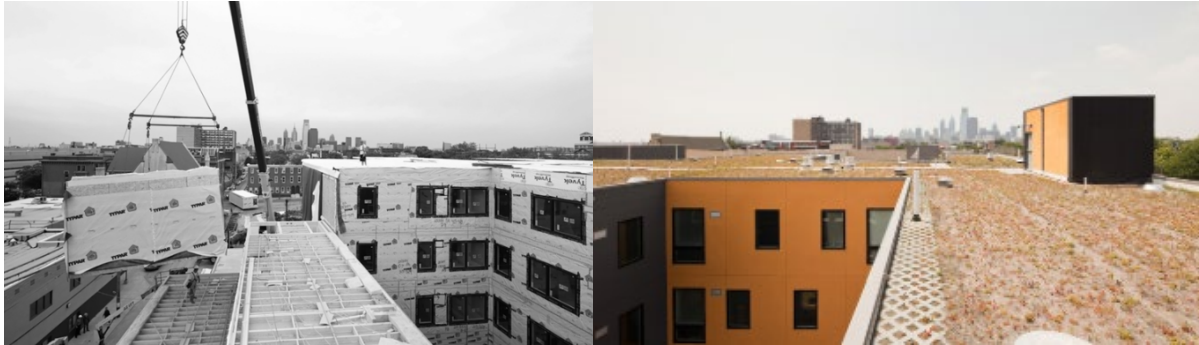


Figure 1.1. Example of Structural Modular Component



Figure 1.2. Permanent Modular Construction | Bathroom Pod | Integrated Modular Design

1.5 Defining Offsite Construction Industry Segments

Ryan Smith, Chair of the OSCC for the NIBS is an expert in the field of modular construction. Experts like Smith group modular construction into two industry segments; re-locatable and permanent modular construction.

1.5.1 Defining Relocatable Modular Construction

Smith states “Re-locatable modular, sometimes referred to as temporary modular, are structures which meet temporary space needs and can be leased in a short-term agreement or purchased outright” (Smith 2016). The MBI, defines re-locatable buildings as, “a partially or completely assembled building that complies with applicable codes or state regulations and is constructed in a building manufacturing facility using a modular construction process” (“What Is Modular Construction? | Modular Building Institute” n.d.). Common types of relocatable buildings include health facilities, school classrooms, job site trailers and more. The 2020 Dodge Data & Analytic report showed that “28% [of respondents] have used relocatable modular construction” (Dodge Data & Analytics 2020). Figure 1.3 shows Fort Lewis-Madigan Army Medical Center’s 30,870 square foot Disability Evaluation facility, which is re-locatable (“SMM Provides Expedited Army Medical Center” n.d.).



Figure 1.3. 30,870 square foot re-locatable modular facility | Photo by SMM

1.5.2 Defining Permanent Modular Construction

Permanent Modular Construction is a permanent solution that is significantly different than relocatable modular construction solution. In the context of this study, “modular” is referencing permanent modular construction (PMC). Smith and Rice (2015) defines PMC as “an innovative, sustainable construction delivery method utilizing offsite, lean manufacturing techniques to prefabricate single or multi-story whole building solutions in deliverable module sections.” Furthermore, the Modular Building Institute (2019) states “modules can be integrated into site-built projects or stand alone as a turn-key solution and can be delivered with MEP, fixtures, and interior finishes in less time with less waste, and with higher quality control compared to projects utilizing only site-built construction.” According to the survey done by Dodge Data & Analytic (2020), respondents forecasted that healthcare facilities will use PMC on healthcare buildings over any other type of building in the next 3 years. The report showed that “38% [of respondents] have used relocatable modular construction” (Dodge Data & Analytics 2020). Figure 1.4. shows a 22,000 square foot permanent modular health services center in Bethpage, New York (“Awards of Distinction - Entry Detail” n.d.).



Figure 1.4. PMC | The Charles Evans Health Services Center | Photo by MBI

Chapter 2: Review of Related Literature

This research aims to discover the drivers and barriers that influence hospital owners to either pursue or not pursue OSC. This literature review takes an in-depth look at the drivers that influence owners to use OSC and the barriers that keep owners from using OSC.

2.1 Publishing Trends Related to OSC

This literature review first provides some insight on how much literature exists on the topic of OSC with respect to hospital projects. Overall, a large amount of literature exists on the topic of OSC, and in recent years there has been a rise in the number of published OSC articles. This trend suggests that the use of OSC methods is also increasing.

An article in the *Journal of Cleaner Production* titled, “A holistic review of off-site construction literature published between 2008 and 2018” provides evidence of increasing publications about OSC (Jin et al. 2018). Jin et al. (2018), used an online citation database called “Scopus” and found that between 2008 and 2010, the number of journal articles published each year about OSC was ten or less. Furthermore, Jin et al. (2018), found that between 2011 and 2015 that number was between twenty-five and thirty-eight. Lastly, Jin et al. (2018), states that “since 2016 the yearly academic publication has been skyrocketing to 68 or more” (Jin et al. 2018).

There are some major industry experts that provide their insights not only about OSC but also about OSC in the healthcare market. Readers could infer that there is an increasing trend to use offsite construction on healthcare projects. For example, the MBI is a recognized industry expert that regularly publishes literature about the topic of OSC in the healthcare market. The MBI has a publication titled “Modular Advantage.” In their August 2016 quarterly publication titled, “Permanent Modular Construction and Relocatable Building Annual Statistical Data,” the MBI published a handful of articles and case studies about the healthcare market and the benefits of

modular construction. The case studies included, a Community Health Center, a Health Clinic, a Dental Clinic Replacement, and a Veterans Affairs Psychiatric Hospital. Overall, their quarterly publication said that, “Many hospitals and healthcare facility contractors are turning to modular, primarily for building components such as bathroom pods and headwalls. However, entire hospitals have been constructed utilizing modular construction techniques” (MBI 2016). Overall, the MBI is one of the primary sources for OSC literature, and MBI publishes a moderate amount of written work about OSC in the healthcare sector.

In addition to the MBI, a handful of well-known companies and organizations, such as Dodge Data & Analytics and McGraw Hill Construction, have conducted and released surveys related to the OSC industry. These surveys are valuable data that addresses the state of prefabrication in the construction industry. For example, McGraw Hill Construction and Dodge Data & Analytics conducted a study and published a report in 2011 called, “Prefabrication and Modularization: Increasing Productivity in the Construction Industry SmartMarket Report.” Dodge Data & Analytics conducted a follow up study and published a report in 2020 titled, “Prefabrication and Modular Construction 2020.” The 2020, Dodge Data & Analytics report summarized the benefits of prefabrication and modular construction. The authors concluded that prefabrication and modular construction have several benefits including, “Improved Cost Predictability, Improved Productivity, Improved Quality, Improved Safety Performance, Increased Client Satisfaction, Increased Schedule Certainty, and Reduced Waste Generated by Construction” (Dodge Data & Analytics 2020). Overall, both the 2011 and 2020 reports spoke positively about the current and future use of prefabrication and modularization on healthcare projects.

Other organizations such as the NIBS OSCC and Falls Management Institute (FMI) have conducted surveys and released useful research reports as well. Apart from the surveys, other

authors have reviewed and summarized important literature about the topic of OSC. As mentioned earlier, Jin et al. (2018) published a comprehensive literature review about OSC articles published between 2008 and 2018. The following sections of this literature review relied heavily on Jin et al.'s literature review, the aforementioned surveys, various journal articles, books, and other academic resources to gain a better understanding of the drivers and barriers related to OSC.

2.2 Benefits of Offsite Construction

Industry experts suggest that benefits such as cost, schedule, quality, and safety are drivers that influence owners to use OSC. As mentioned in the introduction, these drivers influence owners to seek alternative construction methods over stick-built or traditional on-site construction methods. Therefore, subsections 2.2.1 thru 2.2.4 provides a literature review related to cost, schedule, quality, and safety surrounding OSC.

2.2.1 Cost

McGraw Hill's 2011 SmartMarket Report claimed that sixty-five percent of the 809 architects, engineers, and contractors surveyed, said that using prefabrication and modularization decreased the construction project's budget. Roughly forty percent of those respondents reported that using prefabrication and modularization on their projects decreased the construction project's budget by six percent or more (McGraw Hill Construction 2011).

However, OSC does not always save owners money. As mentioned in the earlier section, the OSCC published a report titled, "The Report of Results of the 2014 Off-Site Construction Industry Survey." The Report showed that OSC "has historically not been a lowest-cost solution for project delivery; however, the [survey] responses indicate that it is a cost-effective solution" (OSCC 2014). The survey included 312 respondents from varying disciplines, such as general

contractors, engineers, architects, and owners. Of the 312 respondents, roughly thirty-two percent reported that cost was “the actual benefit realized by using off-site construction” (OSCC 2014).

Smith and Rice (2015) conducted a small study and examined eight case studies, which compared completed permanent modular construction (PMC) against that of benchmarked in-situ construction projects. Smith and Rice (2015) suggested “that PMC projects are on average 11% lower in vertical construction cost compared to conventional methods of construction” (Smith and Rice 2015). Interestingly, the study compared the 150,000 square foot PMC construction of Mercy Hospital to that of a benchmarked stick-built project. Mercy Hospital replaced St. John’s Regional Medical Center (RMC) because a F5 tornado hit St. John’s RMC on 22 May 2011. Smith and Rice reported that PMC project costs of Mercy Hospital were roughly \$240 per square foot compared to a rough benchmark figure of \$340 per square foot. Despite the positive cost analysis, Smith and Rice noted that they needed more cases or data to show a trend that PMC promotes a cost reduction.

Bertram et al. (2019) showed that an OSC approach “has the potential to yield significant cost savings, although that is still more the exception than the norm.” Realizing cost savings is seemed to be the exception rather than the norm because of increasing project complexity. For example, Bertram et al. (2019) states that OSC “requires carefully optimizing the choice of materials; finding the right solution between 2D panels, 3D modules, and hybrid designs; and mastering challenges in design, manufacturing, technology, logistics, and assembly.”

Technology appears to contribute to improving construction costs when combined with OSC. According to AutoDesk, Building Information Modeling (BIM) “is an intelligent 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure” (AutoDesk 2020). As discussed previously, the Dodge Data & Analytics’ 2020

report showed that Building Information Modeling (BIM) use was helpful when combined with prefabrication or modular construction. The report showed that the more a company implemented BIM, the more they would realize cost benefits. For example, twenty-eight percent of companies not using BIM had the smallest degree of improved budget performance, while forty-seven percent of companies who used BIM on fifty percent or less of their projects had a greater degree of schedule reduction. The largest degree of schedule reduction comes from fifty percent of companies who used BIM on fifty percent or more of their projects (Dodge Data & Analytics 2020). Dodge Data & Analytics presented their data in a bar chart as shown in Figure 2.1.

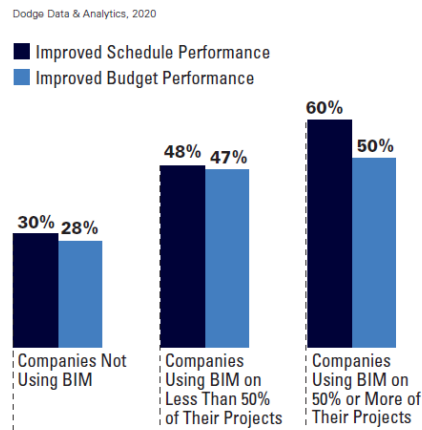


Figure 2.1. Improved Schedule and Budget Performance (Dodge Data & Analytics 2020)

In addition to using technology as a cost savings measure, improving cost by way of schedule reduction appears to be a factor that drives owners to consider OSC. Razkenari et al. (2020) states that “time savings [schedule reduction] directly affects the overall construction costs, such as overhead.” Furthermore, “off-site can offer higher levels of value in terms of quality assurance and corresponding customer satisfaction through time and cost certainty” (Hairstans 2016).

Another area of interest related to cost, which is lacking in research, is the notion of cost certainty or referred to as cost control. MBI (2019) suggests that cost certainty is an added benefit

to using permanent modular construction. Smith and Rice (2015) state that “most stakeholders reported PMC offers a greater control of cost compared to traditional build.” Literature suggests that freezing design may enhance cost control. Razkenari et al. (2020) noted freezing the design early “is sometimes considered a benefit of the modular sector as it pushes design, engineering and planning professionals to provide a well-developed set of plans early on the project, reducing the likelihood of change orders along the process.” The Montgomery Office of Legislative Oversight published a report in 2014 titled “Change Orders in County Government Construction Projects,” which reviewed seventeen capital projects built between the years of 2009 and 2013 and found that change orders increased contract costs by eight percent (Trombka and Scrubbs 2014). Deduction would point out that freezing design could result in less change orders and thus reduce the final cost of the project.

2.2.2 Schedule

A thorough literature review suggests that a decrease in schedule is one of the most reported benefits of using OSC. In fact, reducing the construction timeline is a prominent statistic in many reports. The OSCC published a report titled, *The Report of Results of the 2014 Off-Site Construction Industry Survey*, which included 312 respondents from varying disciplines, such as general contractors, engineers, architects, and owners. Of the 312 respondents, forty-five percent were using some form of OSC on their healthcare projects (OSCC 2014). The survey showed that seventy-three percent of the participants reported that the primary benefit of using OSC was the reduction of the overall project schedule.

McGraw Hill’s 2011 SmartMarket Report claimed that sixty-six percent of the 809 architects, engineers, and contractors surveyed, said that using prefabrication and modularization on their construction projects decreased the schedule. Furthermore, 187 of those respondents said

that using prefabrication and modularization on their projects reduced the schedule by four weeks or more.

According to McGraw Hill's 2011 SmartMarket report, "prefabrication can yield time savings through the ability to conduct work simultaneously onsite and offsite, as well as helping with better coordination among trades" (McGraw Hill Construction 2011). This type of approach is commonly known as fast tracking in the construction industry. An article in the MBI's "Modular Advantage" claimed that fast tracking can help complete a project "50 percent faster than traditional construction processes" ("PMC & RB Annual Statistical Data" 2016). MBI also draws the conclusion that completing projects fifty percent faster increases the likelihood that owners will occupy their buildings fifty percent sooner.

Fast tracking is not the only factor that can reduce the construction schedule. Cutting the need for temporary equipment can also reduce the construction schedule. McGraw Hill's 2011 report states that OSC reduces the schedule by lessening the onsite staging activities associated with the project, such as placing scaffolding.

Weather delays are another factor that can increase or reduce the construction schedule. For example, "prefabrication reduces the risk of on-site disruptions caused by adverse weather through a controlled construction environment" (Wong et al. 2017, 3). Furthermore, with "a controlled construction environment," allows project stakeholders to predict completion dates and control schedules more accurately (Vokes et al. 2017).

Repetition also drives reductions in schedule. The NIBS OSCC provided a case study on the Christ Hospital Joint and Spine Center project located in Cincinnati, Ohio, depicted in Figure 2.2. The NIBS OSCC case study showed that the "main driving factor for the decision to use pods was the repetition of the units to achieve a number that would result in significant quality and

schedule benefits” (WBDG 2017). The project owner needed to complete their ninety-eight-million-dollar, 365,000 square foot new construction and expansion project as quickly as possible. Completing the project as quickly as possible combined with a lack of skilled labor prompted the owner to use an alternate approach to a stick-built construction project. Therefore, the owner decided to use a mix of on-site construction and OSC. This hybrid approach consisted of prefabricating and incorporating over eighty patient bathroom and shower pods into the expansion part of their stick-built project. Figure 2.3 illustrates a finished patient bathroom and shower pod.



Figure 2.2. Christ Hospital Joint and Spine Center, Photo Credit: Tom Rossiter, (WBDG 2017)



Figure 2.3. Prefabricated Bathroom and Shower Pod, Photo Credit: Tom Rossiter, (WBDG 2017)

Smith and Rice (2015) conducted a small study and examined seven case studies, which compared completed permanent modular construction (PMC) against that of benchmarked in-situ construction projects. Their study suggested that PMC can reduce project schedules by an average of forty-two percent. On May 22, 2011, an F5 tornado damaged St. John's Regional Medical Center (RMC) prompting the need for a new hospital that construction stakeholders needed to deliver in record time. The construction team delivered a 150,000 square foot modular hospital in roughly eight and half months as opposed to delivering a stick-built hospital of comparable size in twenty months (Smith and Rice 2015).

Technology also appears to contribute to schedule reductions when combined with OSC. According to the 2011 McGraw-Hill Smart Market Report, "50% of the respondent firms that use Building Information Modeling (BIM) on more than 50% of their projects experienced a schedule decrease of four weeks or more due to their use of prefabrication" (McGraw Hill Construction 2011).

Dodge Data & Analytics' 2020 report showed that Building Information Modeling (BIM) use was advantageous when combined with prefabrication or modular construction. The report showed that the more a company implemented BIM, the more they would realize the benefits of schedule reduction. For example, thirty percent of companies not using BIM had the smallest degree of schedule reduction, while forty-eight percent of companies who used BIM on fifty percent or less of their projects had a greater degree of schedule reduction. The largest degree of schedule reduction comes from sixty percent of companies who used BIM on fifty percent or more of their projects (Dodge Data & Analytics 2020). Unfortunately, Dodge Data & Analytics did not show how much time BIM improved the project schedule.

Fast-tracking, reducing staging activities, environmental controls, repetition, and the use of building information modeling are just a few examples of how OSC helps owners realize schedule reductions. Many owners have deadlines, or they need to meet client demands, or they may even need to get a product out to market before their competitors. Bertram et al., (2019) states that “shorter project schedules are a huge advantage for developers that sell their units in blocks or rent them out. It allows them to begin collecting revenue sooner, paving the way to higher internal rates of return, improved cash flow, . . .”

Another advantage of OSC is schedule certainty. A reduced construction schedule is just as important as having a reliable or predictable schedule. Razkenari et al. (2020) states that “offsite construction has also a predictability factor, which enables construction schedule and costs to be more precisely estimated than in conventional methods.” Predictability and reduced schedule are extremely important as it relates to patient care in an active hospital. McGraw Hill (2011) states that “[projects] on active sites, like a new building in a hospital complex, a reduced schedule minimizes the impact on the rest of the business,” such as patient care.

2.2.3 Quality

An article in the MBI's quarterly publication, *Modular Advantage* said that "manufacturing modular units and components offsite in a controlled environment ensures a high level of quality as well as consistency in construction to meet performance and compliance requirements unique to the healthcare segment" ("PMC & RB Annual Statistical Data" 2016). McGraw Hill Construction (2011) interviewed project owners who said that the "reliability of the quality is a crucial factor in their decision" [to use offsite construction]. Consequently, seventy percent of all respondents in the McGraw Hill Construction survey showed that project quality improvements were a factor driving future use of prefabrication and modularization.

An abundant amount of literature shows that the use of OSC will improve the quality of a project. Manufactures achieve quality standards because prefabrication of offsite building components happens in a temperature-controlled environment. Temperature-controlled environments protect workers and building components from harsh environmental factors, such as weather. According to McGraw Hill Construction (2011) "the lack of exposure to the elements also increases the quality, as does the ability to fabricate in factory conditions rather than on ladders or from scaffolding." Razkenari et al. (2020), states that "At the product level, the controlled environment promotes the use of higher precision machinery and protects materials from adverse weather conditions" (Razkenari et al. 2020).

Furthermore, "quality control is much easier and better in a factory environment than on a construction site which has a significant impact on rework" (Bertram et al. 2019). Bertram et al. (2019) states that "reducing or eliminating rework significantly improves construction schedules, potentially by up to several months." Arguably, reducing rework not only improves the construction schedule but also reduces the construction costs. Lastly, "there is often also the risk

of defects not being identified onsite until many months or years later when it is far harder and more expensive to rectify” (Bertram et al. 2019).

Lastly, there is an assumption that OSC demands more integration and collaboration, which results in a higher quality project or product. According to Smith (2014) “increased integration and collaboration throughout the delivery process can result in higher quality and reduced changes through construction.” As mentioned in the earlier section, NIBS OSCC published a report titled, *The Report of Results of the 2014 Off-Site Construction Industry Survey*. Of the 312 respondents in the survey, roughly sixty-three percent reported that quality was “the actual benefit realized by using off-site construction” (OSCC 2014).

2.2.4 Safety

Safety is an important driver to using modular construction and there are many benefits to its use. More than half of the contractors surveyed in the “2011 Prefabrication and Modularization Smart Market Report,” “reported that safety was an important driver in their use of prefabrication/modularization.” The 2011 report indicated that fifty-eight percent of industry experts surveyed, and who were already using OSC, reported that increased safety was a factor in driving future use of prefabrication and modularization (McGraw Hill Construction 2011). Furthermore, the 2011 report indicated that forty-nine percent of industry experts surveyed, and who were not using OSC, reported that a safer construction site was a factor in driving potential use of prefabrication and modularization in the future (McGraw Hill Construction 2011). The McGraw Hill Construction’s “2013 Safety Management in the Construction Industry”: SmartMarket Report reported that: “the ability to do complex assemblies at ground level or offsite, the ability to have fewer workers on site working on different aspects of the building at the same time and the reduced need to do work at a great height. All of these were widely recognized by

respondents as beneficial” (McGraw Hill Construction 2013). The Modular Building Institute reports that “modular boasts additional safety merits throughout the building process.” Table 2.1 provides a list of the additional safety merits that MBI reported.

Production
Workers are not exposed to harsh weather and elements.
Safety measures can be strictly imposed and are easy to monitor in a factory setting.
The factory employs local workers who are accustomed to the tasks they perform as well as the factory environment.
Installation and Site Work
Fewer contractors and fewer deliveries reduce site disruption.
Less time spent is at the construction site (30-50 percent reduction).
Fewer workers are needed onsite

Table 2.1. Safety Merits of Modular Construction (MBI 2020)

2.3 Barriers of Offsite Construction

2.3.1 Perceptions

There appears to be a negative perception about modular construction. Research shows that colonizers of the 16th century used prefabrication during colonization, and many countries adopted OSC practices during and after World War II (Fenner et al. 2018). According to Fenner et al., (2018) “most of these projects failed in terms of practice and performance, leaving a negative perception in the public, housing market, and architects. (Fenner et al. 2018). Fenner et al., (2018) studied Goodier & Gibb (2007), Samuelsson Brown, Parry, & Howlett, (2003) and concluded that “the industry is trying to overcome this negative stigma by improving construction methods [and] materials . . .”

There are many barriers related to modular construction and some authors have taken the time to analyze previous literature and categorize the barriers of modular construction into a comprehensible structure. Wuni and Shen (2020) found 120 actual and perceived barriers of offsite

construction, which they later grouped into eight main categories that included attitudinal, industry, process, financial, technical, aesthetic, knowledge, and policy. This section focuses on the attitudinal barriers or the perceptions of offsite construction. Wuni and Shen (2020) defines attitudinal as “a behavioral pattern which makes a significant difference in innovation diffusion.” Overall, the authors inferred that there are negative perceptions about the modular construction industry and consequently these perceptions hamper its adoption. Wuni and Shen (2020) found ten out of the 120 barriers were related to negative perceptions. Some of these negative perceptions included “negative sentiments from past failures,” “concerns that architectural creativity will suffer. . .,” and “clients [owners] resistance, conservatism and skepticism.”

Negative or positive perceptions can come in many other forms. For example, in a structured interview conducted by Lu and Liska (2008), participants who included architect and general contractors, perceived that transportation size, transportation cost, and compromised structural integrity were barriers to the use of modular construction. In the same study Lu and Lisk (2008) found that architects and general contractors perceived that the significant benefits of using offsite construction included schedule reduction, quality, improved labor production, etcetera. This suggests negative perceptions and/or positive perceptions influence healthcare owners to either use or not use modular construction on their hospital projects.

2.3.2 Experience

A stakeholder’s experience with modular construction is likely a key factor when considering modular construction on a project. McGraw Hill Construction (2011) provided an excerpt from their Texas Health Harris Methodist Alliance Hospital case study. In the case study McGraw Hill (2011) quoted the director of healthcare services at a major construction group as

saying that “the cost and schedule gains of using prefabrication on a small 188,000-square-foot hospital . . . can be minor, but the experience . . . will pay off on larger projects.”

Razkenari et al. (2020) also assessed the challenges associated with offsite construction and concluded that the “lack of contractor experience was significantly more important than any other challenge . . .” Overall, stakeholders who have modular experience will most likely have better project performance on their projects.

Construction and Architectural education about offsite construction utilized on hospital projects is lacking in the industry. A National Institute of Building Sciences survey conducted by Smith, Grosskopf, and Elliott (2015) found that in design and construction academics, “the most addressed off-site construction typology” was single family housing. Furthermore, the infographics of the survey they conducted inferred that roughly fifty percent of the curriculum in the design and construction academics was related to single family housing for both architects and construction management students. Offsite construction typologies related to healthcare was nearly 40% for construction management students and less than ten percent for Architect students. This lack of education, especially as it relates to hospital construction could impact an owner’s decision to use or not use modular construction on their hospital projects.

2.3.3 Resistance or Buy-in

Resistance to use modular construction may keep stakeholders from using modular construction. McGraw Hill Construction (2011) found that “forty-six% of non-users report not using prefabrication/modularization because the architect did not design it into the project. This might be due to the lack of designer experience or because modular construction limits a designer’s creativity. Wuni and Shen (2020) reported that negative perceptions perpetuate a lack of experience and knowledge. Thus, this lack of experience and knowledge leads to resistance from

designers. Although, their research suggests that designers perceive modular construction as monotonous, they also propose strategies to overcome such barriers. For example, they claim that by improving innovation and the number of “architectural design options” that these options will “. . . eliminate the perception that MiC [Modular Integrated Construction] is recipe for monotony of project outlook and constitutes a threat to architectural creativity” (Wuni and Shen 2020).

2.3.4 Regulatory Code Compliance and Inspections

Regulatory code compliance can raise concerns with respect to modular construction. According to Verzoni (2019), modular construction “has prompted some fire and life safety professionals to raise questions about how the industry is regulated, such as how the units are inspected at off-site fabrication facilities and how final assembly takes place at construction sites.” Furthermore, there is a concern over how, where, or who completes inspections. Verzoni (2019) inferred that code compliance is complicated especially when modular manufactures build units in one state and then transport them to another state for installation. The Modular Building Institute also stressed the importance of stakeholders, especially contractors that they understand the regulatory process if they plan to use modular construction. They stated, “the modular building contractor should already know the regulations that apply to the project based on the address of the physical building site and the agencies that have jurisdiction over that area” (MBI 2021).

Stakeholders are likely quite concerned about regulatory requirements when considering modular construction on their projects. Razkenari et al. (2020) conducted research about the perception of offsite construction and their target population included various stakeholders with varying degrees of offsite construction experience. One of the areas they assessed was the barriers to offsite construction. Using a Likert scale, they asked participants to rank the importance of several barriers, which included: environmental impacts, scale and repetition, capital costs,

regulatory requirements, and others. They found that regulatory requirements ranked the highest in terms of importance to stakeholders, 3.9 out of five on the Likert scale, with five being the highest. In comparison, environmental impacts caused by transportation distances ranked the lowest at 3 out of five.

2.3.5 Transportation

Transportation distance may have a positive or negative influence on healthcare owners to either use or not use modular construction on their hospital projects. Environmental impacts related to transportation may not be as important to owners as other barriers. The Razkenari et al. (2020) questionnaire about the barriers of offsite construction concluded that environmental impacts related to transportation distances ranked the lowest at 3 out of five on their Likert scale.

Distance and location of the modular manufacture from the project site are key factors to consider because transporting modular components can be costly to ship and coordinating transportation is complex. Schoenborn (2012) stated that stakeholders can save costs when using modular construction but warned that owners should consider the offset in transportation costs. Building firms state that the problem with transporting modular components is that modular components are light and bulky; essentially, transporters are charging to ship air (ENR 2006). According to the report of the results of the 2014 OSCC Industry survey, “one of the most significant barriers is transportation, and more specifically, how far away the factory is located from the construction site.” Furthermore, according to the Modular Building Institute:

“Transportation of the modules depends upon some important factors such as the cost and method of transport, travel distance, and weight. It usually is not feasible to ship modules far due to road size and load restrictions. Generally, the maximum desirable distance for transportation of modules is 250 to 400 miles. The costs and transportation difficulties greatly increase for building sites farther than four hundred miles.”

Other challenges related to transportation facing project owners include the distance of fabricators from the project site and owners not informed on the benefits of using OSC. Dodge Data & Analytics states “design professionals point to a shortage of prefabrication facilities close to their project sites and to owners’ lack of understanding of the value of modular construction as the main reason they do not design in these approaches from the beginning of a project” (Dodge Data & Analytics 2020).

Using an OSC approach requires an increased level of communication among stakeholders, especially during the manufacturing and transportation phases. Hsu, Aurisicchio, and Angeloudis (2019) states that “raw building materials are dispatched to manufacturing factories, where they are transformed into modular components that are ultimately shipped to construction sites. As such, there is an urgent and persistent need to maintain close coordination among the manufacturing, transportation, inventory management and assembly sequences” (Hsu, Aurisicchio, and Angeloudis 2019).

As already mentioned, McGraw Hill and Dodge Data showed that construction professionals are using OSC on nearly half of their healthcare projects. Consequently, these results imply that there is an advantage, or benefit, to using prefabrication and modularization. The motivations for any project owner, regardless of project type, is to reduce cost and schedule and improve quality and safety. Modular construction touts these benefits. Yet, data suggests only fifty percent of healthcare projects are taking advantage of this construction method. If hospital projects are in the best position to use prefabrication and modular construction, why are more hospital owners not using this method? There must be benefits and barriers that influence owners to either use or not use modular construction on their healthcare projects. Despite the abundance of research related to offsite construction there is an underwhelming amount of published literature about the

benefits and barriers that influence hospital owners to implement modular construction on their hospital projects. Thus, this study aims to understand the benefits and barriers of modular construction.

Chapter 3: Methodology

3.1 Methodological Approach

The researcher aligned the framework of this study in grounded theory. According to Leedy and Ormond (2019) a grounded theory study is a “qualitative research design in which a researcher collects data relevant to a research problem and uses them [the data] to develop a new theory about a particular phenomenon.” In this case the “phenomenon” is the benefits and barriers that influence hospital owners to either use or not use modular construction on their hospital projects.

3.2 Data Collection Method

Primary and secondary data were collected to gain a better understanding of the research topic. Research began by collecting secondary data through an in-depth literature review which provided a basic understanding of the benefits and barriers that might influence owners to use or not use modular construction. These benefits and barriers included cost, schedule, quality, safety, perceptions, experience, resistance or buy-in, regulatory compliance and inspections, and transportation. After this initial data collection, an interview tool was developed to facilitate collection of primary data for the study.

The target population included experienced industry leaders who are leading some of the largest/top organizations across the country. The research design allotted for a target population that included only individuals that are or have worked on a hospital project. The population included: hospital owners (or their representatives); architects that have work on or are currently working on a hospital project; and general contractors that have worked on or are currently working on a hospital project. Because of their industry experience, these organizations/leaders were able to provide reliable data about modular construction and its use on hospital projects.

Nearly all the participants had incorporated modular construction on a hospital project or had extensive knowledge in the practices of offsite construction.

The sample population was based non-probability and snowball sampling. Non-probability sampling was a favorable choice as it was not possible to gather data from every hospital owner in the United States. Initially the sampling included hospital owners who were operating in California, Oregon, and Washington, such as Evergreen Health, Franciscan Health, and the Military Health System. Therefore, expanding the geographical location increased the likelihood of collecting data for this study; many of the participants in this study worked for firms that provided construction related services nationally. Lastly, snowballing occurred because of interviewees contacting and recruiting other participants.

The interviews of the sample population were semi-structured, and the researcher did not strictly adhere the questions developed for the study. The initial questions on the interview tool allowed interviewees to answer broadly about the benefits and barriers of OSC. Subsequent questions on the interview tool allowed interviewees to answer more specific questions about the benefits and barriers of OSC. Often, responses to the broader question were sufficient, which resulted in eliminating the need to ask specific questions later in the interview. Overall, the interview questions were meant as a guide and thus the interview tool was inherently flexible. Appendix A contains the questions, which were used as a guide during the interviews. The researcher requested permission to record the meetings at the start of the meeting and informed the participants that the study would keep participants names and organizations anonymous. The interviews were recorded using a digital voice recorder. The recordings were later transcribed using an online transcription service. The interview transcripts were then edited to ensure they were coherent.

3.3 Methods of Analysis

The method of analysis was thematic. According to Caulfield (2019) a thematic analysis is “a method of analyzing qualitative data. It is usually applied to a set of texts, such as Interview transcripts. The researcher closely examines the data to identify common themes – topics, ideas and patterns of meaning that come up repeatedly.”

The first interview began with a very well-known and published scholar in the field of modular construction, who is also an educator and has professional consultation experience related to modular construction. The initial interview data provided a solid foundation for the development of categories (or codes) related to the benefits and barriers of modular construction. The SAGE Encyclopedia of Qualitative Research Methods states “codes may also come from a beginning conceptual model, the review of the literature, or professional experience as the basis for coding” (Given 2008). The Coding in this research design was initially based on the first interviewees’ professional experience. The researcher began reviewing the data obtained from the interviews and developed an initial set of codes. During the familiarization process, the codes were refined to develop a final list of codes, which were applied to the data.

A repository was created in Excel to assist in the classification and storage of the data. The transcription data was first formatted in Microsoft Word and copied and pasted into Microsoft Excel. Figure 3.1 provides an example of the codified data copied into Microsoft Excel as seen in column “E.” Column “A”, “B”, and “C” in Figure 3.1 provides an example of how Microsoft Excel was used to codify the data. Column “A” had a drop-down menu that allowed the selection of “BEN” if the data pertained to a benefit of modular construction and “BAR” if the data pertained to a barrier of modular construction. Columns “B” and “C” in the Excel sheet had drop-down menus with a list of codes, such as quality, schedule, labor, and cost. Column “B” contained the

primary code for the data while Column “C” contained a secondary code. The purpose of the primary and secondary codes was to enable tagging comments that referenced more than one category. For example, the data in column “E” on row 492 refers to both cost and labor. Column “G” and “H” provided a transcription timestamp and the interviewee’s pseudo name.

	A	B	C	E	G	H
1	Benefit or Barrier	Code Level 1	Code Level 2	Direct Quote	Time (Do not sort or filter)	Pseudonym
485	BEN	Schedule	Schedule	But when it came right down to the wire, right in March and April, when things had to be built very quickly, you probably know this from talking to the Army Corps, but modular was the way they went, because that was the absolute fastest way to get units that could deliver the oxygen and the ventilators right away. And they had some pretty cool designs that they [Army Corps of Engineers] were able to put in into the field within three weeks.	3652	Sheila Weber and Bently Mcdaniel
492	BEN	Cost & Cost Certainty	Labor	I don't have enough expertise in this area, but my understanding from my own kind of review of the literature, and putting together some of the materials we have for the for the OSCC, is that on net, the factory wages are going to be less than what is paid to folks on site.	4140	Sheila Weber and Bently Mcdaniel
493	BEN	Cost & Cost Certainty	Labor	I have read the same thing [factory wages are less than what is paid onsite]. That [wages] is a factor, is going to cause the trades, who do the building construction, the skilled labor, to balk at the modular construction and, you know, not wanting to switch over to doing it. It is almost a generality that wages in the field, for a site project, are higher than factory wages, but again, there are many tradeoffs.	4202	Sheila Weber and Bently Mcdaniel
494	BEN	Schedule	Schedule	The regularity of work in the factory, from scheduling, to lower wages, to regular hours, you know, is a real trade off, and has proved to be more attractive to a diverse population, rather than someone who is a bricklayer, whose father was a bricklayer, who belongs to a union, and is used to the high wages.	4245	Sheila Weber and Bently Mcdaniel
497	BEN	Quality	Quality	[Related to offering more quality than on site], I think we are, absolutely. [Related to offering more quality than on site], it is more uniform too.	4524	Sheila Weber and Bently Mcdaniel
501	BAR	Cost & Cost Certainty	Economies of Scale	It's probably not a standard you can apply to every project because the benefits are not necessarily there. So there's a scale issue . . . a tipping point of saying, is the project going to give us . . . the benefits of modular construction within its scope, complexity, and duration.	1739	Byron Meyer
	BEN	Schedule	Cost & Cost Certainty	A much larger building complicated, lots of repeated components, [there is] some level of benefit achieved from standardization of construction detailing. So, [there are] efficiencies gained in that. Based on volume, the size, and the extent of it [application of modular	1824	Byron Meyer

Figure 3.1. Classifying Data in Microsoft Excel

Code definitions were developed to help classify each comment, which consequently helped with coding reliability and consistency. Table 3.1 provides a full list of codes and definitions that were developed.

Code	Definition
Application	Comments related to hospital projects that can benefit or not benefit from modular or prefabricated building component (s); comments related to current or potential modular applications; inference that owners are using or are not using modular.
Constructability	Comments related to any aspect of building or assembling modular construction; regardless of design or construction phase
Installation	Comments related to setting modules or prefabricated building components in place
Performance	Comments related to increased or decreased workforce performance
BIM & Technology	Comments related to technology and building Information Modeling (Not related to manufacturing sophistication)
Cost	Comments related to price
Cost Certainty	Comments related to cost control or cost certainty
Delivery Method	Comments related to a particular deliver method
Prefabrication Strategy	Comments related to emerging models of prefabrication, (i.e., GC or SC manufacturing or third-party manufacturer)
Knowledge & Education	Comments related to any aspect related to sharing or needing knowledge or education. Applies to any aspect or process of modular construction.
Experience	Comments related to any aspect related to previously using modular or needing to have experience to make modular work.
Perceptions	Comments related to any negative or positive stigma associated with the modular construction industry; regardless of person or topic.
Resistance	Comments related to any resistance or lack of resistance related to applying modular manufacturing techniques.
Buy-In	Comments related to whether a stakeholder "buy-in" is needed
Labor	Comments related to any aspect of Labor that is related to the workforce; (i.e., reduced labor, processes that minimize or maximize the labor force; reduced or increased wages)
Life Cycle	Any aspect related to life cycle planning, costing, or age of buildings
Manufacturing Technology	Comments related to any aspect of a manufacturer's capability, capacity, or competence (knowledge); can include the lack of manufactures across the US.
Planning	Comments related to any aspect of planning and incorporating modular construction through thoughtful foresight (i.e., planning for transportation or design early)
Communication	Comments related to any aspect of communication between stakeholders which are related to the modular construction project and its processes.
Portfolio	Comments related to applying modular construction on more than one project in an owner's building program.
Quality	Comments related to any aspect quality
Regulatory Code Compliance and Permits	Comments related to any aspect of permitting, inspections, regulations etc., (i.e., transportation, building codes, design etc.
Safety	Comments related to any related to safety
Schedule	Comments related to any aspect that increases or reduces schedule
Transportation	Comments related to any aspect related to transportation regardless of topic (i.e cost, size, schedule, location, distance, or installation)

Table 3.1. Coding and Definitions

The purpose the coding system allowed for a systematic tagging (or coding) of the data, which were later filtered and analyzed for recurring themes. A mind mapping software was used to assist in the development of themes. Figure 3.2 provides an example of the mind map technique. Table 3.2 shows a list of the resulting themes, which were used as an outline for Chapter 4.

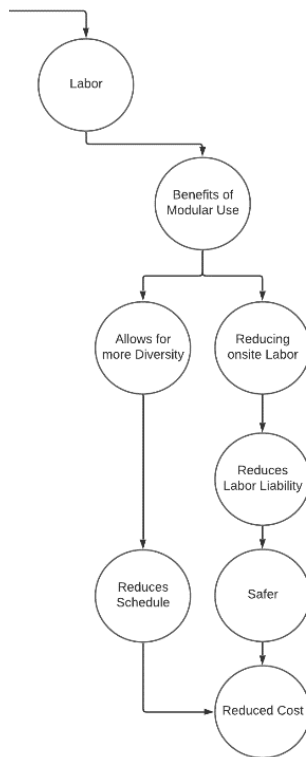


Figure 3.2. Thematic Analysis – Mind Map Example

Code/Theme
Cost
Cost of Modular Construction
Capital Cost
Cost Certainty and Economies of Scale
The Demand for Modular Construction and Cost Savings
Miscellaneous Cost Savings and the Impact on Healthcare
Labor
Drivers to Use Modular Construction
Benefits of Using Labor in a Factory
Potential Barriers to Using Modular Construction
Schedule
Quality
Safety
Planning and communication
Design
Planning early and understanding scope
Replicating/standardizing design
Building Information Modeling and Technology
Delivery Method
Knowledge
Perception
Education
Experience
Resistance or Buy-In
Regulatory Code Compliance
Transportation

Table 3.2. Thematic Analysis - Themes

Chapter 4: Results

4.1 Introduction

As mentioned in the methodology section, the interviews were aimed to get the perspectives of experienced industry leaders. The focus of the interviews was about seeking the benefits and/or barriers of modular construction practices as it relates to hospital construction projects. The industry leaders in these interviews have a vast knowledge of experience and are, or have, worked for the most well-known organizations across the country. Furthermore, many of the interviewees have extensive academic knowledge related to the construction and manufacturing industries. The author gave pseudonyms to all participants. Table 4.1 shows the participants' pseudonyms and their current role in the industry. The researcher interviewed twelve participants and interviewed two of the twelve participants on two separate occasions (Shawn Todd and Phillip Jennings).

Interviewee (Pseudonym)	Role
Byron Meyer	Director of Health and Senior Architect working for a major architect and design firm
Kevin Elliott	Former federal government employee in charge of military hospital planning, design, and construction. Currently a consultant for healthcare related construction projects
Maddison Nelson	Senior Project Manager working for a major construction company
Sam Taylor	Executive Director and Senior Architect working at the Medical Office Building Center of Excellence for a major healthcare organization
Phillip Jennings	A Senior Director of Construction and Engineering working for a major healthcare organization
Stephen Erickson	Prominent senior architect working for a large federal government construction agency
Shawn Todd	Prominent expert in the field of modular construction; author, educator, and consultant in the field of modular construction
Sheila Weber	Prominent architect associated with a government institution that works to resolve construction problems on a national level
Bentley McDaniel	Project manager associated with a government institution that researches and educates about OSC practices
Walter Greer	Director of Design Phase Management working for mega construction company
Jim Stanley	Director of Preconstruction Services works for mega construction company
Doug Oliver	Senior Director of Integrated Services works at the corporate level for a mega construction company

Table 4.1. Pseudonyms for Interviewees

The first interviewee was with Shawn Todd who is currently the Director of the School of Design and Construction at a University in the United States. Also, Shawn Todd is a founding partner in a consulting organization which provides advice for companies and helps them become knowledgeable in the space [Modular Construction Industry]. Todd has been researching modular construction for roughly fifteen years and authored several books and articles about the offsite construction industry, permanent modular construction and much more. His research focuses on strategies to take advantage of market barriers and opportunities and grow the modular construction industry. The Department of Veterans Affairs and Sutter Health among other project owners have benefited from his consultation and research. The researcher used data collected from Todd's interview as the initial basis for coding in this study.

Overall, this study confirmed that there are many important benefits and barriers related to modular construction. The number one benefit that hospital owners can achieve from using modular construction is a reduced construction schedule. Owners can achieve cost savings on projects as a result of a reduced construction schedule; however, owners are not likely to save directly on modular construction costs. Quality is incredibly important and can positively influence hospital owners to use modular construction. Safety is important but not likely a primary influencer on an owner's decision to use modular construction. Overall, the construction industry needs to work to update current building codes, which will result in more adoption of modular construction on projects. Improving education and experience could result in better modular knowledge, which would likely lead to an increased use of offsite construction.

4.2 Applications, Constructability, Building Components & Performance

A notable finding during the interviews was about the “application” of offsite construction on hospital projects. Comments about the application of modular construction included: the potential, current use, or trend of a particular building component(s); aspects of constructability as it relates to design and/or ease of assembly and installation; and comments related to how constructability improved workforce performance. The focus of this study was not seeking to understand what or how many types of prefabricated building component owners were using. Nor was it seeking to explain the aspects of constructability or improved workforce performance. Nevertheless, the discussion surrounding the applications of modular construction proved insightful because it provided an overall sense of the current trend of modular construction on hospital projects.

Overall, interviewees indicated an increased trend in the usage of modular construction. Various comments were related to current or potential applications of a particular building component(s). Interviewees mentioned items such as bathroom pods, patient rooms, headwalls, prefabricated exterior and interior panels, chiller packs, and biosafety laboratories (BSL). Some interviews provided examples about the current and potential applications of offsite construction. For example, one interviewee suggested that there are opportunities to incorporate the most basic prefabricated building components (such as hospital refrigeration equipment) to the most innovative prefabricated building components such as BSLs. For example, Jennings, a Senior Director of Construction and Engineering working for a major healthcare organization, stated, “a chiller is a good example because a lot of chillers are factory packaged assemblies that just get shipped in . . . same thing with heavy transformers and stuff like that.” For the more innovative building components Jennings stated, “there are some phenomenal BSL companies that are doing

BSL trailers. Why could not we say, hey, we want a BSL company to do a BSL three module for us.”

Interviewees unanimously regarded that the current and potential applications of OSC is, and can be, a benefit to hospital projects. Although not empirical, there was a general sentiment that OSC is positively trending and will continue to trend. Furthermore, all the interviewees displayed a great degree of enthusiasm when talking about the topic of OSC. From an empirical standpoint, interviewees provided numerous examples about the use of prefabricated components. This supports the idea that there is likely a positive trend which shows an increased use of OSC on hospital projects. As an example, Byron Meyer, a Director of Health and Senior Architect working for a major architect and design firm, said this, “We are working on a project that will be done in 2021. It is the new patient pavilion . . . [It is] a \$1.5 Billion dollar job . . . and it had an absolute extensive offsite construction process.” A quick search revealed that the OSC aspects of the project included “five-hundred-and-fifty-nine mechanical racks, 504 bathroom pods and 47 zone valve boxes for medical gas are being constructed in a 60,000-square-foot factory-like warehouse. . . and trucked to the site two miles away” (Goodman 2019).

4.3 Cost

This study found that cost can influence owners to use modular construction. However, to realize the cost benefits of modular construction, owners should incorporate modular early in the planning or design phase. Factoring in modular construction early on will lead to understanding the scope of the project sooner which leads to reduced change orders. Reducing change orders will improve cost control/cost certainty which leads to an overall cost benefit. Another factor related to cost is the notion of standardization/repeatability. With standardization/repeatability comes cost certainty and economies of scale; both of which lead to cost benefits. With

standardization/repeatability comes economies of scale which leads to production efficiencies, schedule reduction and revenue generation. Ultimately these factors will lead to cost benefits.

4.3.1 Cost of Modular Construction

Hospital owners may perceive that the cost of modular construction is less expensive than stick built construction and consequently it may influence them to use modular construction. Modular costs are not a straightforward topic, and owners should consider many aspects related to cost and modular construction. Overall, there is no “material cost” benefit to using modular construction over stick-built construction; regardless of how or where the owner builds a modular because theoretically the suppliers are charging the same price for materials (Figure 4.1). The only caveat might be if manufacturers are ordering a large volume of material; otherwise, the cost of materials for both onsite and offsite are likely to be equivalent.

Greer, the Director of Design Phase Management who works for mega construction company, stated that there is a perception that modular construction should cost less. However, Greer also inferred that costs related to modular construction are complex; especially since every project is different and every owner has their own standard or requirement. He suggested that the cost of modular is not straightforward, otherwise owners would just use modular construction rather than traditional construction all the time. Greer went onto say “when you start to put the dollar sign on a prefabrication, or modular effort, the extents of where those dollars can be applied, or how you analyze it, is so wide open.”

Overall Greer suggested to be cautious of data that states modular construction “saves” you money. Instead, he illustrated how stakeholders should view cost saving by stating:

“the really interesting thing that I have seen more and more, is not talking about the savings in terms of dollars, [it is when industry talks] . . . about [savings] purely in terms of hours diverted . . . like if you can save 10,000 hours’ worth of construction activities on site. And we move that to an offsite environment. Well, we just inherently know that is better. (Greer)”

Oliver, the Senior Director of Integrated Services who works at the corporate level for a mega construction company, provided his thoughts about modular costs and suggested that it is hard to understand the cost effectiveness of modular construction. He argued that whether its volumetric or prefabricated panels, manufactured by third party manufacturer or contractor, and/or whether any those entities have used a modular approach, it is difficult to discern how trade partners have or will price the work.

Todd stated that many owners seek a cost reduction on their projects, but stated cost is not really a benefit. Furthermore, he stated, “I will say, in our research it has shown to be higher cost” (Todd). Kevin Elliott, a consultant for healthcare related construction projects and former federal government employee that oversaw military hospital planning, design, and construction, stated that cost is not really a benefit. He stated, “I don't think you save any money doing this [modular construction]. You might [save money], but the components are what they are; you are going to still spend money on building the componentry” (Elliot). Elliot went on to say that, “you still have to hoist it, you still have to lift it, you still have to [pay for] cranes, you still have to be able to put it together.” Bentley McDaniel, a project manager associated with a government institution that researches and educates about OSC practices, indicated that “I think from a cost savings perspective, . . . I do not think the data necessarily bears out that modular will necessarily save you more money.” Maddison Nelson, a Senior Project Manager working for a major construction company, also said, “there is a price factor in the decision [to use or not use modular], I think, there could be varying experiences with the price of modular versus conventional build” (Nelson).

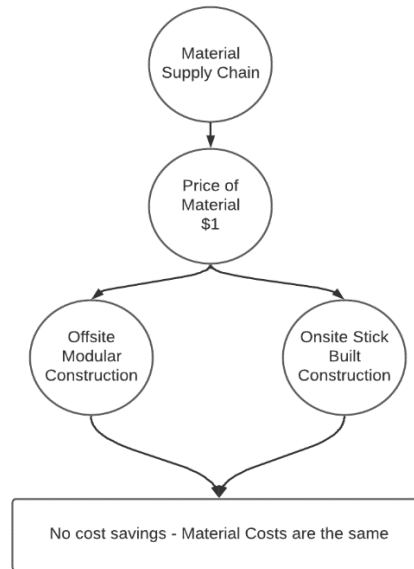


Figure 4.1. Cost of Materials

4.3.2 Capital Cost

One noteworthy finding, and not particularly well documented or obvious in the academic literature review is that capital costs related to modular construction might be a barrier. When asked whether price would influence an owner to use or not use modular construction; McDaniel noted that using modular construction requires more upfront capital than typical stick-built construction. He stated, “it is not so much about the costs themselves; it is when they [capital costs] are effectively due. It is not that the capital costs are more or less, per se, it is that [modular construction] requires a greater upfront draw percentage. So, they need more capital put up front in a modular construction [project] than in a typical site built [project]” (McDaniel). He suggested that upfront capital costs could be a potential barrier to using modular construction. All the interviewees touched on capital costs in one way or another and as the reader will see in section 4.4.6 owners are likely to try to strategically spend their capital smartly.

4.3.3 Cost Certainty and Economies of Scale

Standardization and repeatability support economies of scale and ultimately cost certainty. Todd suggested that cost control (i.e., controlling the number of change orders) and cost certainty (known costs) is an area where a project owner really benefits from modular construction. By having a well understood scope of work, project owners who use modular construction on their hospital project will have reduced number of change orders. Reduced change orders will lead to more cost certainty on projects, which is consequently a cost benefit that can influence hospital owners to use modular construction (Figure 4.2). Todd stated, “. . . cost certainty is more important than lowest cost, particularly on healthcare projects. If you do not have cost certainty, the change order costs can be astronomical if scope is not caught during the bidding process” (Todd).

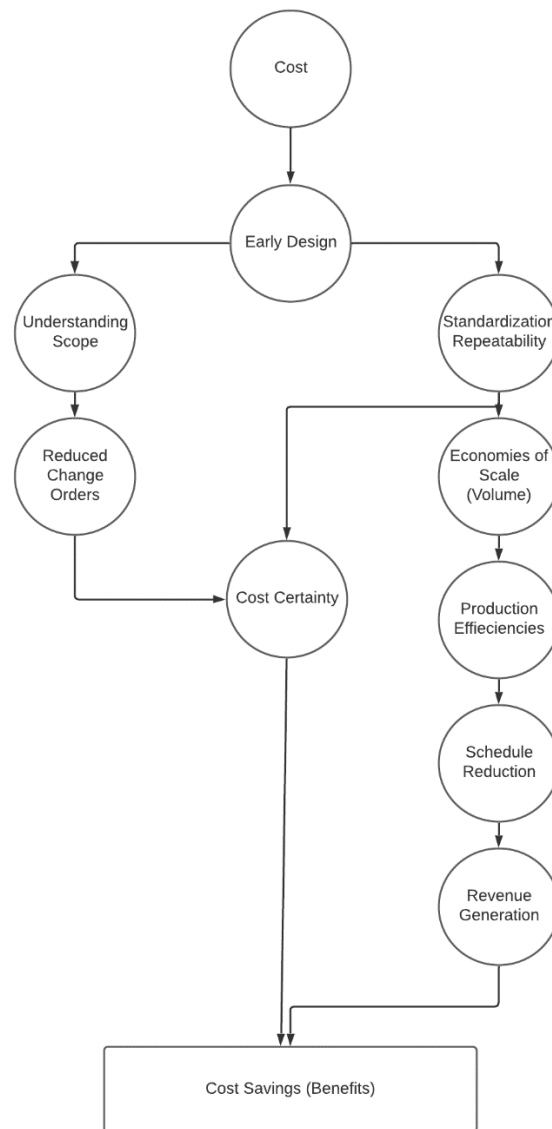


Figure 4.2. Economies of Scale and Cost Certainty

Standardization and repeatability support economies of scale which results in more production efficiencies and consequently can lead to schedule reduction on hospital projects. Owners can benefit from schedule reductions as this leads to owners generating revenue on completed projects sooner and a reduction in project indirect costs. Nelson said that there are number of factors to consider with respect to cost and inferred it is not just about the price of building components. For example, she stated, “. . . there is also a schedule component. The more

modular units you have, the more the cost is going to be more neutral to stick building. If you save on the schedule; that becomes an advantage for an owner on their operating costs, they can begin operating and generating revenue earlier” (Nelson). Jennings had similar thoughts about cost savings. He offered the “Total Cost of Ownership” concept, which is an analysis of the total project cost, which looks at numerous aspects of a project: such as reducing cost, schedule, life cycle, and others, with the goal of generating revenue sooner. Jennings inferred that it might be advantageous to pay more for a modular project if it completes the project sooner.

Todd stated, “so the only way to get [the] real benefit of economies of scale . . . is to be able to have enough volume, or through put, in a factory, or a series of factories to service a project.” With respect to volume, he believes that “using modular on a 50-unit hospital . . . [is] questionable whether you can get the benefits of modular construction but if you are building a . . . two hundred, bed hospital that's a different story. It starts to really price out about that point” (Todd). Oliver also echoed Todd’s comments when he stated, “If you are manufacturing it can't be one off, so manufacturing approaches have a lot of front-end structure, [such as], facilities, equipment, etc. While that means it needs a lot of throughput and volume to realize the savings.”

Meyer also inferred that economies of scale was a factor when deciding to use modular construction. He stated, “there's a scale issue . . . a tipping point of saying, ‘is the project going to give us . . . the benefits of modular construction within its scope, complexity, and duration’ . . .” (Meyer). Meyer suggested that larger hospital projects have more repeatability and are more likely to benefit from economies of scale, which could potentially save owners time and money. He stated that a “five hundred bed hospital is going to have all those rooms and standard patient toilet pods and . . . you're going to repeat it five hundred times. So, there's economies there. But in a

smaller . . . ambulatory facility . . . it is going to repeat [and] you will probably have some exam rooms . . . but how many, [is it] 10-15?” (Meyer).

Similar to what Todd suggested, Elliot also mentioned that an owner might save money by “replicating the process.” Nelson also suggested that economies of scale are a factor in cost; especially as it relates to modular patient rooms or exam rooms. Her contracting firm investigated them, but she stated that there are some building components that are still “cost prohibitive.” She went on to say, “you need a large repetition to make it work [and] . . . most of the reason that we would not do those [patient rooms] is financially [they are] too costly at this point” (Nelson).

Todd explained that standardization/repeatability has more cost certainty whereas custom projects tend to have more uncertainty for the modular manufacturers. Therefore, modular manufacturers are increasing the price for taking on the risk for customization. Todd stated, “If they [modular manufacturers] have a product that they know they can mass produce, and produce a lot of those boxes, those volumetric boxes, yes, price per box will go down, certainly.” Todd suggests that manufacturers are able to reduce risk by “organizing their labor to be efficient [and] productive, create an assembly line, [and] procure suppliers to provide material at a reduced rate.

Stephen Erickson, a prominent senior architect working for a large federal government construction agency, mentioned that it was possible that cost certainty could influence an owner’s decision to use modular construction. First, he claimed that there are more items that a contractor must bid in the field environment as opposed to a factory environment; an inference that bidding on stick-built projects has cost uncertainty. He stated, “I can easily see a module getting built on a factory floor with a couple trades working around each other on their feet, versus [workers onsite] [who are] hanging overhead walls or maybe [hanging] gypsum up on one side; I got ladders moving around, I got jack wagons trying to walk down the hallway. . . [etcetera]” (Erickson).

Furthermore, Erickson believed that repeatability contributes to efficiencies, an inference to cost certainty and economies of scale. He described the following example about a MEP module: “I mean, in a bidding environment, if we showed clearly . . . a module that gets replicated three hundred times, a good contractor, they are probably going to do a mockup with their subs and say . . . how fast can we build this stuff and get a much tighter bid. If we are in that kind of fixed price environment, you will get better cost certainty” (Erickson).

Nelson suggested that cost certainty can influence owners to use modular construction. She stated that “the decision [to use modular construction] needs to be made very early in the process” (Nelson). She suggested that this can lead to design challenges; however, she also suggested that “cost certainty gets pushed up in the process” (Nelson). She provided this example: “When you typically design . . . the restroom [bathroom pod] in a very early stage of design, because it has to be manufactured in [a certain] timeline to be factored in [to the overall project], . . . your costs are known a lot earlier with the modular construction” (Nelson). With respect to cost and incorporating the design early on, she suggested that by not incorporating modular construction it could be “cost prohibitive.” Nelson concluded by saying that design changes during the manufacturing phase will impact cost certainty. Todd also said that “if you make that decision [to use modular construction], during bidding, you are going to have negative cost and schedule implications on the project, we have shown that in our research.”

Todd stated that during his study of sixteen modular projects they found that change orders happened less often with modular construction versus traditional stick built. He stated, “we found that they [modular projects] had an average of six to twelve change orders on average per project.” Todd concluded by saying that change orders are “significantly reduced, because you have to define all those things, [the details and scope], right at the design phase.”

4.3.4 The Demand for Modular Construction and Cost Savings

As more owners implement modular construction the more the price of modular construction will decline. Todd inferred that modular construction is a higher cost than traditional construction because there is nothing forcing owners to use modular. He provided an example of a developer in San Francisco who is using modular construction. Todd stated, “I was talking with a developer out of San Francisco. . . [which has] a lot of work going on in modular there. Anything you can do to try to control that [cost] and get in as quick as possible to reduce the amortization on a loan for land, anything you can do, modular or some other method, it's looked on as beneficial.” He also suggested that Seattle is at a point where the use of modular may increase as well. Overall, his comments suggested that a shift in market conditions will force owners to look at alternative construction methods, which will eventually decrease the cost of modular construction.

Erickson implied that the more you implement modular construction, the more likely it is that an owner will save cost by using modular construction. He said initially though, “if you are trying to get cost on the first time, [you] do it, you are probably not going to get it” (Erickson). He indicated that any time an owner tries something new (such as modular construction) there will be risk and added cost. He also inferred that as the construction industry moves towards implementing more modular construction, the more likely prices for modular construction will decrease. For example, he stated, “I think once we get down the road, this will become more common and we are going to say, ‘yeah, I do need to go this way and save money and industry will shift with us.’ But initially, . . . the risk is too high. . . we are going to need to commit to paying a little bit more for some period or number of projects” (Erickson). Consistent with Erickson comments, Todd stated:

“We are still in a point where there's not enough of them [modular manufacturers], that it benefits them to price any differently than how the traditional construction industry is pricing. What you'll notice is rarely do they [modular manufacturers] pass on any savings to the contractor [or] to the developer.”

“I think ultimately, as it becomes more competitive, and there are more modular manufacturers, and it is showing some benefit and there is more demand. Then you will see those prices start to drop because the manufacturers are going to be competing with one another and competing against traditional construction to get the prices lower.”

4.3.5 Miscellaneous Cost Savings and the Impact on Healthcare

The remaining portion of this section are related ideas about costs savings that one of the interviewees brought up during the interview. The author felt that it was important to capture these unique ideas because the author did not consider the ideas during the literature review or when developing the interview questions.

Sam Taylor, an Executive Director and Senior Architect working at a Medical Office Building Center of Excellence for a major healthcare organization, suggests that his organization is theoretically saving money in other unique ways by using prefabricated building components. Taylor and his team use their kit of parts approach which is like picking standardized prefabricated building components from a catalog. By using this approach Taylor suggest that his organization can give back time to people by reducing the number of meetings. He guessed that the traditional construction approach had five hundred meetings versus one hundred with the kit of parts approach. He went on to illustrate his example:

“So, imagine if you can standardize what we are doing and limit those user group meetings to just choices A or B, or do you want this piece of equipment or that piece of equipment, or this piece of equipment comes with three options, which one do you need based on the procedures you are going to do in the room. If you can limit the conversations to that and let us just say we come up with one hundred user meeting, we just gave back four hundred hours [per] individual, and meetings are full of people” (Taylor).

Taylor also stated that not only were they giving back time, but they were giving back time to “the organization for people to actually do what they were hired to do; [the] clinicians [who are] providing care to patients.

Taylor provided a reasoning for the importance of reducing costs on their healthcare buildings, which consequently partially supports the reasoning for conducting this study’s research. Taylor states that the focus of his organization is about preventative healthcare and making healthcare affordable for everyone. Taylor suggests that healthcare has a “tremendous capital appetite and we have to figure out how to reduce the cost of what we are doing; [construction].”

Taylor concluded his cost saving comments by sharing some general cost information related to their latest project. As indicated above Taylor and his team use a kit of parts approach, which is something new they developed while delivering their latest project. Taylor stated “From a budget and schedule standpoint, we just barely missed the budget goal, just a few \$100,000 over a \$61 million budget. So, for all intents and purposes, we were on budget, but we were slightly over, [even though] we had to design the building in flight.” Taylor implied that his organization would continue using an alternate prefabricated construction due to the potential reduced cost. Taylor stated, “we were pretty pleased with the fact that the first project almost achieved the target; whereas we know that the next projects will. So, we are saving costs, we are doing it faster, and we are meeting the overall objective of the organization, which is to deliver care faster and reduce the cost to our member.”

4.4 Labor

There were three primary areas related to modular construction and labor discovered in the study. These three areas can potentially influence hospital owners to use or not use modular

construction. The three areas included: drivers to use modular construction; the benefits of using labor in a factory setting; and potential barriers to using modular construction with respect to labor. Labor shortages and labor cost were the main drivers to using modular construction. The benefits of modular construction are numerous, and they all lead to reduced costs. A notable discovery is that modular construction allows for more diversity and leads to reduced schedule and reduced costs. Using modular construction can lead to reduced onsite labor, reduced labor liability, and a safer onsite working environment, which all consequently leads to reduced project costs. Lastly, modular construction could be a barrier as it is an industry disruptor that creates labor shortages and potentially creates a threat to unions. Figure 4.3 illustrates the Mind Map analysis.

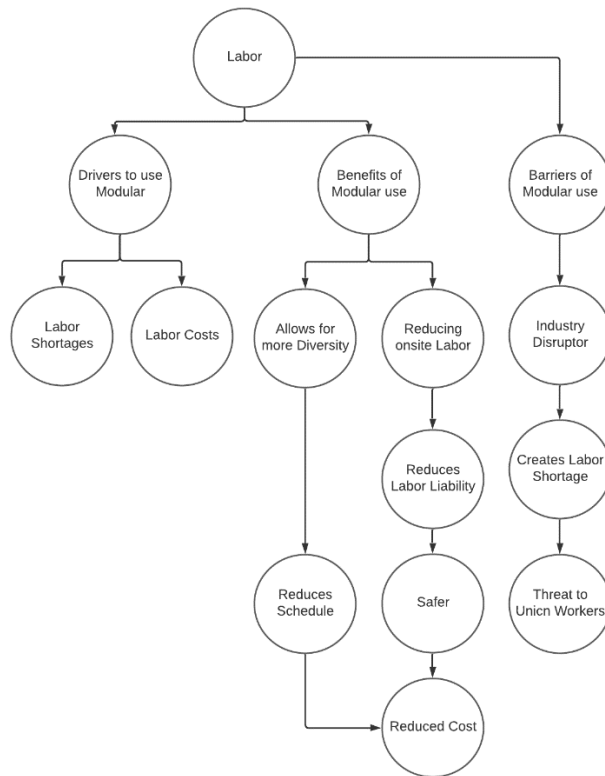


Figure 4.3. Drivers, Benefits and Barriers of Labor

4.4.1 Drivers to use modular construction

Labor cost and labor shortages were the main drivers to using modular construction. Jennings provided an example related to a previous project that he was responsible for when he was working for the government. His example illustrates labor costs with respect to using modular construction on a healthcare project. The project was in another country and the planners were discussing the best course of action for the construction methodology. The planners were considering using modular construction on a healthcare project and shipping the building components overseas. They contemplated the labor expense to build the headwalls and install the medical gas lines in the United States versus building the headwalls and installing the gas lines overseas. Jennings stated, “why would we spend money and time to have construction occur . . . [overseas], as opposed to have construction occur in . . . [the United States and then] put it on the barge and ship it . . . [overseas].” Jennings argued that it would cost more money to keep the medical gas technician overseas for four years versus having the technician install the medical gas lines in the United States. He went on to say the technician can “fabricate [the] panels in the [United States] and then ship the panels . . . [overseas] and then go down for three weeks and do all the final connections” (Jennings).

When asked about whether labor shortages influenced owners to use modular construction Todd stated, “I think we're seeing that sort of a desire to go more modular now across building types is related to the lack of labor in the industry.” Jennings suggested that labor shortages were due to labor migration and suggested that we have a more mobile workforce. He likened labor shortages to the gold rush and unfortunate natural disasters. He suggested every time there is a natural disaster, workers migrate to the area to put their talents to use; thus, creating a vacuum or shortage of laborers. His example illustrates how labor shortages might influence owners to use

modular construction on a healthcare project. He stated, “we have a much more mobile workforce than we did 10 years ago, 15 years ago, 20 years ago, except for COVID. . . people in Washington state are short on drywallers in eastern Washington, because they all went down to Florida after the hurricane.

Nelson also indicated that labor shortages were driving contractors to use modular construction. When discussing labor shortages during the interview, she suggested there is a shortage of trade labor and contractors are having a tough time finding people. She went on to say that contractors are “. . . trying to find ways to help reduce the quantity of labor on site.”

Simmons also believed that a labor shortage might influence owners to use modular construction. He suggested these shortages are going to lead to contractors developing more efficient labor practices. He stated, “When I am out on a project site, I got a lot of factors in play, which are going to hurt my labor efficiencies. Whereas, if I know I am short [on labor], . . . I could produce a much more efficient assembly process and that crew is going to be working on the assembly line, not the footprint of a major medical facility.” Simmons didn’t feel that labor shortages was a major factor but felt that when the “. . . contractor starts sharpening their pencils on bids . . .” that it would be a factor” (Simmons).

4.4.2 Benefits of using labor in a factory setting

A notable comment about diversity was an important aspect that warranted a place in this study. Sheila Weber, a prominent architect associated with a government institution that works to resolve construction problems on a national level, mentioned that manufacturers can incorporate more women into modular factories. She suggested that women on average are physically smaller than the typical male construction worker and might not be able to do some of the more physically demanding tasks required on the jobsite. However, she inferred that factories are more amenable

to all physical characteristics, allowing for accessibility to the workforce. She concluded by inferring that a diverse workforce allows manufacturers to work around the clock to produce modular building products, which could help reduce a project's schedule.

Oliver mentioned that the current construction workforce is aging and suggested that modular construction allows the construction industry to "tap into a different labor pool." With respect to modular construction and third-party manufacturers, Oliver stated, "if you develop it the right way, with the right design information level of detail, you can then empower folks that wouldn't be in the trades or have that skill set to do some of the work." He illustrated an example where drywallers might do electrical or plumbing work. Overall, he inferred and concluded that under the right circumstance, projects gain efficiencies when "craft workers become multi-trade."

McDaniel suggested that a modular factory is safer than working onsite. He stated, [modular construction] . . . is just a safer working environment for workers. So, I think, from a liability standpoint, there should be an advantage for owners there as well [working safely in a factory]. As McDaniel suggested a reduction in liability assumes that using modular manufacturing could reduce insurance related costs. During Jennings interview when talking about safety, he stated that "safety is a big factor for image and for insurance purposes."

Using modular construction can lead to reducing onsite labor which consequently leads to reduced project schedule and costs. Meyer suggested that owners are not saving on material but rather the labor costs when it comes to using modular construction. He stated, "the labor is saved, you can save time, and you will save a whole lot of money for the owner." Myers suggests that offsite construction can lead to reduced onsite labor and make coordination easier. First, he illustrated how many onsite trades are simultaneously working to construct a project's bathroom. He stated, ". . . look at how many disciplines you have in a toilet room. You have plumbing, you

have carpentry, you have cabinetry, you have electrical, you got low voltage and you got finish . . . [such as] tile [or] maybe [you got] solid surface [etcetera]. [You have] all those [workers] climbing all over each other in a seven by eight room.”

He continued his illustration by suggesting that coordination issues and complex tasks are abundant when you are working onsite. He stated, “. . . the ductwork had to be routed around the steel and then the piping had. . . three more angles [added] to get it around the ductwork. The complexities just go on and on.” Overall, the benefits of modular construction are numerous, and they all lead to reduced costs.

4.4.3 Potential barriers to using modular construction

Using modular construction could be a barrier as it is an industry disruptor that upsets the labor market, and potentially creates a threat to unions. Jennings stated, “there is some internal conflict that [using modular construction] creates for us in the industry because we got to figure out how we are going to employ those people [that we don’t hire for onsite work]. Jennings goes on to say, how do we keep the unions happy on a project for a hospital, which very often comes with government money, when we are . . . doing all of this work offsite somewhere else and not using the local community.”

Elliot had similar thoughts about how modular construction is a potential industry disruptor. He stated “the necessity to do integrated construction techniques in a modular unit, sort of steps on trade labor. Because the factory . . . needs electricians, carpenters, plumbers, drywallers fitters finishers, [etcetera].” Though Elliott mentioned that there are organizations that are lobbying on behalf of the modular construction industry and this is creating some tension within the local municipalities where there is a strong union presence. He stated, “[modular manufacturers] are

doing something that is essentially taking work away from others. In a way that is not about construction, it's about the labor and the economics of the labor force. . .” (Elliott).

Stanley, the Director of Preconstruction Services who works for mega construction company, also stated something similar when talking about negative perceptions about modular construction. He stated, “if you ask our union brothers and sisters, some of them have a negative connotation on prefab because it's taken work out of their hands and limiting employment opportunities. That is one of the barriers potentially, depending on your market. (Stanley)”

One last important note related to the union topic is that not everyone agreed that modular construction poses a problem for unions. Todd stated:

“It used to be that Labor unions played into this [labor issues that influenced owners to use modular]. But that [concern] is also going away now because there is not a lot of labor. There is so much work and they are [labor unions] trying to stay busy. And a lot of these factories, these modular factories, that become union . . . that concern is largely gone away that was there maybe 5-10 years ago, might hear lingering still, but it's not really an issue” (Todd).

4.5 Schedule

One of the questions this study sought to answer was whether there were any aspects of schedule that might influence an owner to use or not use modular construction. The section presents the main findings that the author found during the interviews.

The number one benefit that hospital owners can achieve from using modular construction is a reduced construction schedule. Todd stated that a benefit that has “certainly been well published is schedule savings and that's the number one benefit [of modular construction]. If you want to get done by a certain date, or a healthcare system must deliver . . . a certain number of beds by a certain time. . . [using] modular is a good way to accomplish that. He went on to say that “for the most part, that [schedule reduction] is usually the key driver in a modular project” (Todd).

Todd stated, “In my studies, we are showing on average, about 35-40% time savings, which is quite significant on housing projects.” [and] “I don't know a modular project that comes in slower . . . except when we've had major problems with supply chain or weather or something like that” (Todd).

Both McDaniel and Weber also suggested that reduced schedule was a benefit that influenced owners to use modular construction. McDaniel stated, “that schedule is really kind of a big benefit that folks are looking for really compressing the time to operation.” Weber stated, “when you are doing modular to achieve the full benefit, you can plan your schedule more carefully than you do with site built, simply because your stuff is being assembled mostly in a factory, as opposed to on site where you have potentially more labor issues, you also have weather issues and [overall] it is just easier to get a tighter schedule, with modular construction.”

Greer inferred that schedule reduction is “not necessarily [about] compressing the true construction durations, but actually making construction related activities in parallel, like building in two different spots. He suggested that working on site in parallel with offsite manufacturing can not only lessen or “level [labor] resources” but can help with backlog and scheduling. Oliver also agreed that offsite construction can reduce the schedule. However, he said you must define the schedule period. He suggested that owners will not save time using modular construction during the planning and design phases but stated, “if you're talking about shovel in the ground to operational, absolutely no question.” He concluded by saying that modular construction requires more upfront design work, and the team should complete the design work before starting on the foundations and prefabricating the modular portion. Overall, Oliver stated, “if you want the benefits of offsite manufacturing, you must give up something, and that means . . . designing further before you start that work.”

Taylor referred to a hospital project that his organization recently completed and suggested the modular construction offers schedule saving over traditional stick-built construction. He stated, “we delivered it in 24 months, typically, it would take us 32 to 36 months to deliver a project of that size. So, we did well with the acceleration in terms of the delivery of the program” (Taylor). As discussed in the cost section; reducing the schedule has a positive impact on costs. Taylor stated, “If we can improve the productivity on the site, during construction, if we can shorten the construction duration [by] six to nine months, like we did on the first project . . . we know those are cost savings opportunities for us.”

Nelson also stated that modular construction reduces the schedule. She stated that “there's a [schedule] savings, especially when you incorporate it with other fabricated elements. A hospital project that her company was working on opened six weeks early. She stated that “we used not only prefabricated . . . pods, [but] we [also] used prefabricated head walls and foot walls, we used prefabricated racks, . . . so those were [some of the] prefabrication elements [we] used on that project” (Nelson). For this project Nelson suggested that they were able to reduce the schedule because they incorporated all those components, not just bathroom pods.

Overall Erickson believed that a reduction in schedule influences owners to use modular construction. Similar to what Nelson stated, Erickson also mentioned that hospital projects can benefit from modular construction but stated that projects require a multitude of modular components, not just bathroom pods. He stated, “If we only do the bathrooms, and a facility is modular, what about all the other MEP tied to it. If I am going to have a contractor rent a factory or warehouse space to only do the bathrooms, I actually may not see the savings that I am expecting by going modular” (Erickson). Erickson concluded by suggesting that modular construction can

have schedule and cost saving if applied “to the most detailed labor-intensive components” on about half the project.

Delays can impact the installation date of modular construction. Sometimes permitting, design, and other issues can cause delays, which results in an unplanned installation of modular components, which can fall into unfavorable seasons or weather conditions. Todd stated, “when they [stakeholders] don't understand the process . . . all of a sudden, your set dates are now moving into the [harsh weather] season . . . [which ends up] causing a lot of problems [and] if it is very windy, or very snowy, or very rainy, you would not want to set boxes on the jobsite on those days” (Todd). Todd concluded by saying that that not only does this cause “some serious delays” but it also has some financial impacts to the owner.

Implementing modular construction after developing the design or bidding documents is a barrier that may influence owners not to use modular construction. Todd stated that, “if you make that decision [to use modular construction], during bidding, you're going to have negative cost and schedule implications on the project, we have shown that in our research.”

4.6 Quality

One of the questions this study sought to answer was whether there were any aspects of quality that might influence an owner to use or not use modular construction. The section presents the main findings about quality that the author found during the interviews.

Jennings suggested that he thinks quality is something that influences owners to use or not use modular. However, he stated that cost and schedule are of higher importance than quality (Jennings). Nevertheless, he stated that quality is about “total cost of ownership” (Jennings). He explained that total cost of owner is about asking how long a modular project is going to last versus that of a stick-built project.

Taylor believes his healthcare organization can “get a higher quality with the prefabricated components because they are done in a shop.” Taylor and his healthcare “look beyond just the design and construction of a project.” His facilities team works together to ensure that they are selecting long lasting maintainable products (Taylor). Taylor stated, “we do work with our own internal facilities operations staff, to ensure that the decisions we make about: how cabinetry is built, and about what finishes we use, and about what flooring we choose that we make the right decision so it can be maintained and that it lasts for us as well.” Taylor and his organization support their quality decisions based on the “overall cost, long term ownership and funding” (Taylor).

When asked whether Nelson thought quality was a barrier, she stated, “I can't say that I've had that impression” (Nelson). Nelson suggested that a benefit to modular construction was “quality and consistency of the work.” She said by shifting people from the onsite to manufacturing facilities helps control quality. Erickson made similar comments when he stated, “all of your trade’s workers are not on a ladder . . .they are on the ground [and] in factories, your quality control is much better. He also stated that it is challenging to put a metric on quality. However, he did conclude that the more you build something the more you are going to learn from it. He stated, “if you and I are going to build the same widget one hundred times we are going to learn, and those first couple might be a little bit different [but] by the time we get to thirty and beyond, the quality is going to be much, much higher. Overall, he believes that this same concept would be beneficial if applied to hospitals.

McDaniel’s suggested that one of the three big benefits of modular construction included quality. McDaniel’s commented on quality and stated, “your quality control should be higher and if it is done right, it should save you on change orders, and should save you time to correct down

the road.” With respect to quality, both McDaniel and Weber suggested that offsite offered more quality than onsite and Weber stated it was more uniform.

Meyer compared quality with respect to finishes that occur with onsite construction compared to that of offsite construction. He stated:

“If they're [subcontractors] on site, and they wait till they are each done and they go back and do a little work, they let that settle someone else comes in, it's just an every room looks a little bit different, the grout isn't done, the detailing isn't perfect [But], if you do it in an air conditioned or heated warehouse, and everybody just does their pieces like an assembly line, they come out completely consistent, completely plumb, straightforward, [and it is really] fast” (Meyer).

Meyer also inferred that modular construction offers a quality product that an owner would have had to pay more if a contractor built the same product onsite. He stated, “for the same amount of money, you're getting a better-quality product. What that means when you do punch at the end of the job and you go through the inspection, you find fewer mistakes, which means there is fewer stuff to fix, which saves time and money” (Meyer).

4.7 Safety

One of the questions this study sought to answer was whether there were any aspects of safety that might influence an owner to use or not use modular construction. The section presents the main findings that the author found during the interviews.

Nearly all the interviewees suggested that safety was a benefit to the OSC process. When asked about the overall benefits of modular construction, McDaniel and Weber suggested that safety was a benefit. McDaniel went on to say, “doing things in the factory environment sets things up for a safe and productive working space for the folks who are working on these [modular projects].” Stanley suggested, “[modular construction] is a more controlled environment, and the more work that can be done, not in variable conditions to the job site with a variable workforce is

going to be safer overall.” Stanley also stated that “that there is a moral imperative to reducing injuries for construction workers” and also inferred that, safety is the number one benefit of modular construction.” Taylor supported the idea that there are safety benefits related to premanufacturing. He stated, “I believe there are safety improvements that we make by having premanufactured components that can be lifted or put into place without having to utilize so much on-site construction and where there really is more assembly that is being done in the field” (Taylor). He stated that he believes that his healthcare organization is creating a safer environment.

Nelson supported the notion that safety is a benefit of modular construction. She stated, [another benefit to modular construction] “is safety improvement, because you're doing repetitions work at the factory versus the work in the field, which is constantly changing”. Nelson suggested that there were less injuries compared to that of stick-built construction. She stated “think about the manufacturing environment, . . . you are not having to climb up on ladders and do things. She inferred that safety in manufacturing environment was possible because of repetition and everything being at waist height. She contrasted the factory environment with a field environment and stated “you have multiple trades in one spot, trying to get them in and out [schedule them efficiently], [workers are moving] up and down ladders, [there are] moving parts, and [workers are] working with each other. You don't have that in that manufacturing environment.”

Jennings illustrated that field environment is more dangerous than the field environment. He related the field environment to a “dynamic high-risk environment [where you have] timber on the floor, holes for stub ups, any number of things could be there [or even] accidentally touching a copper pipe that, that the welder was just working on”. He contrasted that to the safety of a manufacturing environment. He said that there are safety mechanisms in place such as “yellow stripes on the floor” and equipment with safety “laser detectors” which keeps people from getting

hurt. He argued, “that prefabricated modular may be safer because you are going to do it in a safer environment, because it is a static environment” (Jennings).

Jennings went on to say that “safety is a big factor for image and for insurance purposes.” Meyer stated that “a builder will tell you the more workers that they have on site, the increase for injury, mistakes, coordination, and delays.” He correlated a contractor’s performance with safety by saying, “we measure how many days of injury free on a site as a measure of how well a builder’s doing” (Meyer). McDaniel also suggested that safety is advantageous to an owner from a liability perspective, which could reduce labor costs.

Despite the suggestion that safety was a benefit to using modular construction, some interviewees, like Jennings and Todd, suggested that it was not a factor that influenced owners to use modular construction. Jennings noted that while there it may be safer to build at the factory it was not necessarily safer to install modular components on site. He contended that there is a lack of experience or awareness when it comes to assembling the offsite product on site. The following paragraph illustrates his point about this lack of awareness.

“before prefab and peri-fab, [workers] may have done that work in 15 knot winds and not thought anything of it, but now they are dealing with panels that are 30% larger, and they are 10% lighter. So, the sail area is different, but now they [workers] are dealing with panels that are 30% larger, and they are 10% lighter. There is going to be a learning curve associated with [installation]. [Panels] are going to be easier to handle but you are more likely to pull back muscle because the wind could catch it more easily” (Jennings).

Jennings summarized his comments about safety and thought that overall prefabrication is safer because of the factory environment. Though he did reiterate and made inferences to onsite assembly and awareness by stating, “getting into the repetition of it makes it a little bit easier,” and thus, safer.

Overall, Jennings did not believe that safety was a factor that influenced owners to use modular construction. He stated, “[safety] is not a decision factor, and maybe it will become one with data, but it is not the decision factor in deciding to go with modular.” Todd had the same general impression when asked whether he thought safety was a factor that influenced owners to use modular construction. Todd had a slightly better outlook as it pertains to influence and stated “I think it is a driver, but it is probably [rated] the lowest of the four [Schedule, Cost, Quality & Safety].

4.8 Planning and Communication

One of the questions this study sought to answer was whether there were any aspects of planning and communication that might influence an owner to use or not use modular construction. The section presents the main findings about planning and communication that the author found during the interviews.

4.8.1 Design

This study found that design could influence an owner’s decision to use or not use modular construction. Overall, the study found that to realize the cost and schedule benefits of modular construction owners should incorporate modular early in the design phase. Design repetition and standardization also stood out quite prominently in the interviews. As discussed in the cost section, incorporating modular construction early on leads to better understanding of scope and delineation, which leads to reduced change orders and improved schedule. Planning early allows designers to replicate and standardize the design which leads to efficiencies not only in design but in construction. Creating efficiencies leads to improved schedule and cost benefits.

Incorporating modular construction after the design has started or making last minute changes to the design after manufacturing has begun is not advantageous. Incorporating modular construction after the design has started or making last minute changes to the design leads to increased change orders and has negative impacts on cost and schedule. Other barriers related to design and modular construction are freezing design early, limitations on customization, and complications. Freezing design early limits the architect or owner in making design changes. The desire to customize design on a modular project leads to increased schedule and costs. Lastly modular design can complicate the incorporation of certain design elements such as smoke walls, firewalls, acoustical walls, and others.

4.8.1.1 Planning early and understanding scope

Early planning is a critical success factor related to modular construction. Owners that do plan for modular construction will not receive the benefits that modular construction could potentially yield. Inversely, early planning can lead to owners realizing the benefits of modular construction. Oliver offered a noteworthy comment which other interviewees did not mention. With respect to barriers and planning, Oliver suggested that one barrier to modular construction is the actual project team. He suggested that often the make-up and experience of a project team changes from project to project and new project teams take time to get integrated. Overall, he suggested that it takes time to get people integrated, especially on modular projects that have a lot of detail (Oliver). Overall, Oliver inferred that integration & detailed planning, coupled with cost commitments and learning new approaches to modular construction, puts a lot of pressure on these teams. Stanley had similar thoughts related to planning barriers. He suggests “that the amount of information you need to generate and the number of decisions you have to make early in a job to pull off prefab is daunting. (Stanley)” Oliver concluded by stating, “So you overlay [these

pressures/issues] with a whole new cast of characters [and the] cards are stacked against you. (Oliver)”

Hospital owners typically include the “user” of the hospital into design reviews and other design related tasks. A user’s input during design, especially about space requirements and equipment choices can drive up equipment and project costs, reduce cost certainty, and ultimately impact the schedule. Jennings stated, “Being able to have that conversation, and this kind of ties in with knowing what you want upfront [during the design phase], identifying those things [such as equipment] that you know you are going to make a decision later. Jennings gives an example where the user of a major construction hospital is deciding on what type of Magnetic Resonance Imaging (MRI) machine they want installed. When designing the room that houses the MRI machine, Jennings suggests increasing the overall space requirement for the MRI by 25 percent. Increasing the space requirement for the MRI will offset any potential increases in equipment size due to advances in MRI technology. Increasing the size of the space during design allows owners to have more cost certainty and alleviates any last-minute design changes. Overall, Jennings inferred that owners should communicate with the users of the hospital and plan for modular construction early on.

Meyer suggested that certain modular building components require special attention and proceeded to illustrate an example about modular ceiling raceways.

“Those ceiling raceways I am talking about, these are big chunks of space that have to go up. So how do you make sure that there is enough space in the corridor that is unobstructed to make sure they fit all up there . . . you got to make sure that the column bays are wide enough, the ceilings are high enough, corridors are wide enough and there is enough space to get the equipment into basically lifted into place. That all has to happen very early on” (Meyer).

Meyer provided another illustration with respect to bathroom pods and mentioned the importance of early planning and design. He stated, “regardless of where the toilet pod goes, that

has to be decided very early on as well because you got to make sure that the toilet room itself meets code requirements and the functional uses for patient care.”

Transportation restrictions and regulations impact design. To illustrate the importance of early planning, Jennings provided an example where an architect might be designing within the confines of a 31 x 31 architectural grid. He suggested that you can incorporate many rooms or functions within this grid. However, he stated, “a 31 x 31 [grid] does not fit on a truck unless you break it into three and a half pieces. There has got to be part of the conversation of, well, where does this joint occur, where does the vapor joint occur, how do you make that fit in there” (Jennings). Todd also suggested that designers should consider transportation. He stated, “every state has its own department of transportation regulations. You must find the most restrictive state along your route if you are crossing two states. You may have to design the whole project in architecture based on the transportation width allowance of the most restrictive state on your route” (Todd). Overall, Todd suggested that research shows that the earlier the owner decides to go modular the better (Todd).

Freezing design could be a barrier to the use of modular construction on a hospital project. Nelson stated, “if you're not able to freeze it early enough, then it doesn't make sense to do it [modular]. [If you] get too far down the road [and] . . . you are not making this decision, but you have construction documents completed, it is too late. It just becomes very difficult to incorporate at that point. Oliver stated that “if the culture [users of the healthcare system] isn't aligned with the benefits of this type of [a modular] approach” then they will not implement modular construction. However, Oliver went on to infer that if the entire organization supports the modular approach then offsite construction would be much more successful. He concluded by saying “it has to start

with that cultural alignment in the approach of the organization. [Once that happens] then they will have the tools to manage the users to say we're freezing design.”

Freezing design also limits the ability to make design changes. Nelson suggested that design limitations might influence an owner not to use modular construction and reasoned that “because you have to lock in earlier that might limit some design flexibility” (Nelson). Todd also mentioned from his experience owners tend to want to make changes/decisions as the project goes along, and he inferred that this is not conducive to modular construction. He stated, “freezing those decisions is really important, but in my experience, I don't think a lot of healthcare owners want to freeze design, they like to make this decision as far out as possible” (Todd). Greer also mentioned that users of a healthcare system are known for making changes. Taylor also concurred that freezing design is not favorable from an owner’s perspective and inferred that owners make changes because of equipment related technology changes.

With respect to freezing design not everyone agreed with the idea of freezing design. According to Meyer freezing design is an antiquated term. He stated, “the perception of freezing the design and handing it in an unaltered state to the builder is a really old mindset” (Meyer). He suggested that the involvement between the designer and builder should happen early in design and well before construction starts. He suggested that the builder is likely to build mockups to work through any design issues. He stated early involvement includes, “building mockups . . . and testing it out, making sure that it's the right way to do that, whether that's a room or ceiling rack; it [design] is not ‘it is frozen, now go build it’” (Meyer).

Todd suggested that trying to incorporate modular construction after design is complete is too late. He stated, “If you make the decision to go modular, after design development, in the architecture phases, you will have negative cost and schedule implications to the project. That has

been shown in research. So that is a big reason that the real important time to make those decisions is right from the beginning with the design team, not once you finish design.”

Lastly, as already mentioned in the cost section modular construction reduces the number of change orders. Both Todd and Nelson mentioned that defining the scope of work in the design phase reduces the number of change orders. Weber suggested that modular construction “can make change orders more difficult at times.” McDaniel also suggested that if the team does not think of something, or does not plan modular early enough, then the modular “process could have large ripple effects down the line.”

4.8.1.2 Replicating/standardizing design

Replicating and standardizing the design leads to efficiencies not only in design but in construction. Taylor stated that user preferences vary between the various geographic regions of his hospital organization. He stated that replicating and standardizing their healthcare projects is a challenge, but they have managed to incorporate a standard design, nationally. Taylor went on to say “we can do that [our design process] almost in days, rather than in months that it is taken in the past. So, on the [our] project, from the time we started our design process, five and a half months later, we were into the agency with a set of documents for their plan review, in five and a half months.” According to Taylor, it still took them a little bit of time because it was there first time using prefabricated components. Construction took as long as it normally would have as well, but Taylor inferred that their next project would go much quicker.

Greer suggested that repeatability is not necessarily a result of a contractor’s or a designer’s efforts; rather it is a result of the requirements driven by the owner. He suggested that the owner wants to create efficiencies with the healthcare staff, and this leads to setting up and/or designing

standardized rooms. Greer concluded by stating that this approach will “pay dividends” to the owner over the life of the building.

Greer inferred that almost all hospitals projects are using panelization, but from a repeatability perspective, volumetric design is where the construction industry needs to focus more of its attention. He mentioned that the projects are seeing more volumetric modules like exam rooms and bathroom pods. Overall, Greer inferred that the construction industry does not employ volumetric as much as panelization but suggested a repeatable volumetric design is a benefit to a hospital project. Nelson also illustrated her experience with respect to repeatability and volumetric bathroom pods. She stated, “if you're working on a hospital, [repetition] typically . . . [coincides with a] patient room [or] a joint patient room. So, a lot of discussion of the ‘same handed versus opposite handed’, ‘nested on the inside of the building versus on the outside of the building’.” Nelson not only considered the need for repetition, but in her example, she stated that early planning was important. Nelson stated, “there are some big decisions to be made early in the process that impacts the ability to use prefabricated bathroom pod.” She concluded by stating, “The more consistent that design, and the more consistent the layout, the better it's able to be planned for prefabrication.”

Customization design on a modular project leads to increased schedule and costs and therefore seems to put some limitations on design. Nelson stated, “if you think about it [modular] more like . . . manufacturing an automobile. If you can make it with limited number of options, it is going to go a lot faster. If you have a bunch of customizations it is going to take longer, because each unit or each manufactured item is going to have to have its own customization; so, it stops the production.” Oliver also illustrated a point about limited customization using Toyota as an example. To summarize, he inferred that Toyota is in the manufacturing business and not in the

business of “one-offs.” Toyota needs to produce a certain number of units to become profitable. Therefore, he inferred there needs to be standardization and volume with respect to modular construction.

Modular design can complicate the design and limit design flexibility. Nelson stated, one of the things that you [the project team] will run into is the smoke and firewall' [which] has to be contemplated, and that adds a little bit of complexity to the modular construction [project]. She also noted that firewalls and acoustical requirements can factor into design flexibility” (Nelson). Nelson illustrated how repetition can lead to efficiencies and cost benefits. She stated, “. . . the way you drive down cost and your timeliness . . . is you look for every efficiency you can get, and you find ways to repeat what you are doing. If I can make one design decision, and replicated across 100 bathroom modules, I can focus a lot on that one decision, and then put it in production and go.”

Another limitation related to design flexibility is volumetric design. Todd suggested that long spans such as lobby spaces and others are not conducive to a strictly volumetric design. Furthermore because of a hospital’s complexity he went on to say, “depending on how the hospital's laid out and how it's envisioned, it's just not a good solution for some designs” (Todd).

4.8.1.3 Building Information Modeling and Technology

One of the questions this study sought to answer was whether there were any aspects of building information modeling and construction related technology that might influence an owner to use or not use modular construction. This section presents the main findings that the author found during the interviews.

One interviewee stated that Building Information Modeling was not influencing an owner’s decision to use modular construction. Todd stated, “I don't think it [BIM] influences [an owners’

decisions to use modular] very much. It is unfortunate because it should more.” Todd also spoke about BIM use from the manufacturer’s perspective. He said, we did a study and found . . . most of the factories [are] just barely taking up [integrating] Revit software [into their processes], but it is not very common. So no, it is not really a requirement right now, it should be more and more, but it is just not.” Another interviewee agreed with this overall sentiment and stated, “I think that there's a great deal that could be done, especially with BIM enabled construction techniques” (Elliott). Elliott suggested that bleeding edge BIM processes could improve modular construction processes. He said, “I think personally, that BIM enabled predesign work and manufacturing work, especially potentially 3D manufacturing might actually accelerate some of this [modular construction] techniques. It is not proven, you are not going to find a giant 3D printer to do hospital bedrooms anyplace yet, but it is coming” (Elliott).

When asked whether he thought BIM would influence an owner’s decision to use modular manufacturing, Erickson stated, “Oh, for sure . . . we are definitely not leaning into them [owners] as much as we should.” He inferred that anyone who has used Computer Aided Drafting (CAD) or BIM experience knows that using these tools makes it easier to replicate design. Erickson stated, “for anyone that has done them [BIM Designs], [where] I draw something really well, and I make it a model or a block . . . and then I replicate it . . . [for] anyone that has used CAD or BIM, [they] know that is the way to go” He summarized by saying, “if I can design it, this simply, I should be able to build it as simple as well” (Erickson).

Taylor provided a real-world example where his healthcare organization was implementing BIM. His organization is currently working with a mechanical, electrical, and plumbing contractor out of Southern California, and they are developing an auto routing and auto sizing software program. He stated, “we are actually now using artificial intelligence and a bot, not a robot but a

bot to take a building design once the PAV [program aggregation and validation] set of drawings is done, once the basic parts and pieces of the building have been assembled” (Taylor). His organization has standardized their clinical modular design, and they have developed a detailed space program, which “identifies the function that takes place within a room, how many occupants there are, what kind of lighting load it has, etc.,” (Taylor). The MEP subcontractor incorporates this modular design and detailed space program data into their software program. Taylor stated, [this] “allows the three-dimensional drawings to be read by the software and by the bot, and it designs, the sizing and the routing of the ductwork for the entire Heating, Ventilation and Air Conditioning (HVAC) system [and] it does the same thing for the plumbing system.” Currently, Taylor’s organization is working with the MEP contractor to incorporate the data for electrical distribution. Overall, Taylor’s example illustrates how his organization is using BIM to design and draw distribution paths for MEP in their modular design.

4.8.2 Delivery Method

One of the questions this study sought to answer was whether there were any aspects of delivery methods that might influence an owner to use or not use modular construction. The section presents the main findings that the author found during the interviews. Overall, there was no consensus on which delivery method was the best for modular construction. However, the interviewees generally accepted that some sort of integrated approach was best suited for modular construction.

Todd stated, “In my first book back in 2010, I thought, and it was shown in the early modular projects that you had to have an Integrated Project Delivery (IPD) project delivery model to, to have greater levels of success.” Todd believes that IPD makes a lot of sense on “complex and capital-intensive projects.” Sometime back in 2004 and 2005. Todd sat on an American

Institute of Architects (AIA) leadership group and they wrote the first structure surrounding IPD. He mentioned that hospitals were the primary users of IPD back then and they are still today. Since writing his first book about modular construction, he no longer believe[s] that IPD is the optimal project delivery method to deliver on modular” (Todd). Todd went on to say, "I believe that any delivery method can work, if the owner drives the process, and tries to ensure that the players and the stakeholders have mutual agreements for collaboration and sharing of information. That can be just as successful as an IPD system in my estimation . . ." Todd concluded by suggesting that a design-build delivery method is a “happy-medium” to modular construction and overall, he inferred that risk and responsibility was the key to a successful modular project.

Taylor suggested that his organization uses something like an IPD; they call it an IPD, but it is not a IPD in a traditional third-party agreement sense. Taylor stated, “we still use a contract with the architect and the contractor. We encourage them and we create an environment where they partner as much as possible” (Taylor).

From a government contracting perspective, Erickson suggested that civil works projects are the only “collaborative” delivery methods; all others project types are firm fixed price or design build. Simmons suggests that there is a fear of losing control, and therefore the government is still hanging on to the traditional delivery methods. He stated, “[with respect to the] the federal procurement processes today, and not to say we cannot get there, but the easy button is to not let designers and constructors talk. So that is a significant barrier for entry [into modular construction] that I see” (Erickson). During the interview, Erickson’s position was in favor of putting more modular into government projects and overall concluded by saying that there is need for collaboration between the designer and builders on modular projects.

As mentioned previously, Meyer and his organization constructed a \$1.5 Billion dollar hospital project, which had “an absolutely extensive offsite construction process.” Meyer stated that his organization used an IPD method on this project. He stated that their IPD method was a success and inferred that it was successful because everyone shares the risk and responsibility; he dubbed the delivery method the “ring of fire.”

4.9 Knowledge

One of the questions this study sought to answer was whether there were any aspects of knowledge that might influence an owner to use or not use modular construction. The section presents the main findings that the author found during the interviews.

Overall, the main finding is that with education and experience comes knowledge. Knowledge leads to having a full understanding of offsite construction, which leads to less resistance, more buy-in, and positive perceptions of modular construction (Figure 4.4). The initial analysis separated education, experience, perceptions, resistance, and buy-in into categories but later combined these terms into one category: *knowledge*.

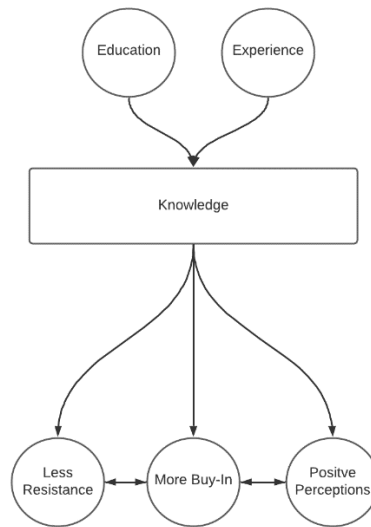


Figure 4.4. Knowledge Impacts Modular Construction

4.9.1 Perception

Stanley stated that he has heard there could be a negative perception tied to modular construction. However, he stated that he does not really see it in medical facilities. Although, he did say “when we talk about prefabrication, or pre-engineered anything with a lot of your customers, they think, metal building, they think, slapped together. And there is a connotation there that I think might carry over a little bit to medical facilities. (Stanley)”

Perceptions could be a barrier to implementing modular construction on a project. Erickson provided an illustration building components that fabricated offsite and then shipped onsite for installation. He stated that the project team found mold in the some of the connections and he suggested that issues like these create negative perceptions about modular construction. He argued that these situations are a barrier to the implementation of modular construction; especially in a hospital environment where the owner expects everything to be spotless or clean.

Weber mentioned that the negative mobile home perception of modular construction, which she inferred is synonymous with poor quality, is still a big problem. Todd stated, “I’ve done

a lot of surveys on [barriers] . . . over the years. . . [and the barrier] that continues to come out is perception issues. . . [and] that [perception] takes a while to overcome. There's been a negative perception for years, certainly.” Jennings also inferred that there is a negative perception of modular construction, where architects and others think that the quality of modular construction is poor, especially when it comes to constructability. He stated, “. . . from just a constructability perspective, you run into the architects and the customers saying, oh, ‘it is prefabricated.’ [However], they have not gone to look at what [modular] panel consists of [and] they have not gone to look at how, beautifully clean some of those things [modular building components] could be because they think about the steel shed in their backyard” (Jennings). Jennings believes that people need to get past the negative perceptions and start thinking about “understanding the requirements” and how to get “healthcare into the hands of the of patient sooner” (Jennings).

McDaniel suggested that there are negative perceptions of modular construction but offered that there are fewer negative perceptions related to modular construction in the commercial setting. He suggested that negative perceptions about modular construction is still evident because people are asking questions like, “are factory-built products as good as site build?” McDaniel stated, “. . . the answer is yes, but it is just really making sure people understand,” [and] “. . . there are still specifically a lot of lenders who need to understand that these [modular components] are just as good as site built or traditionally built projects.”

Other negative perceptions related to modular construction revolve around the idea of where an owner procures modular manufacturing. For example, Greer suggests that when an owner starts procuring modular construction outside their state or outside the country it upsets the local community and thus leads to negative perceptions about modular construction. Greer suggests that

procuring outside the state or purchasing from other countries takes away jobs from the local workforce.

A negative perception that Oliver commented on that some people tend to see a lack of creativity with respect to modular design. However, he suggested that he has seen modular designs which are indistinguishable from traditional stick-built designs. He also illustrated that sometimes residential modular construction fabricators do not wrap or waterproof modules well enough before shipping. He illustrated that sometimes you can see the Tyvek [waterproof membrane] not properly secured and flapping around, ultimately exposing the insulation as it is traveling down the road. Thus, many people see the building components exposed to the elements. It seemed that Oliver's illustration was inferring that there is connection between poorly weatherized modular building components and mold and consequently this leads to a negative perception.

4.9.2 Education

Overall, the negative perception of modular construction exists but is getting better. Todd suggests that a focus on education and awareness about modular construction will help correct the negative perception associated with this construction type. Todd goes on to say that design architects and design engineers need more education on the Design for Manufacture and Assembly (DfMA) process and that the industry needs to learn more about how to design with the manufacturer. Even General Contractors need more education and awareness of modular construction.

All the interviewees felt that education was important in influencing stakeholders to adopt modular construction practices. Taylor stated that “. . . we have to change, we have to focus on change management and education, to train the entire industry to think differently about how we build.” To do this some organizations have their own healthcare “thinktanks” or “Centers for

Excellence” which help with educating various stakeholders about modular construction. Taylor stated, “we have got a Hospital Center of Excellence, we have a medical office building Center of Excellence, and we have an infrastructure and renovation Center of Excellence.” Jennings, who was involved with the U.S. Government, also stated that the government had their own think tank for Healthcare design.

Some organizations put together literature or guides for healthcare owners. McDaniel was working on a project in conjunction with an agency from the U.S. Government. He stated, “We did a lender toolkit with [this Government Agency] over the last year, and that was something they were very interested in, [which] was kind of understanding the benefits of modular construction” (McDaniel). McDaniel went on to state the importance of education and informing the industry. He stated, “I think there is a continued need for research on sort of the benefits per se, because I think a lot of them [research into modular construction], although they've been somewhat quantified, really needs to be a further in-depth kind of analysis on some of this stuff” (McDaniel).

Todd there are limitations to in-depth data analysis because data is just not available. He stated, “all you're [likely] going to get is probably a dozen or so academic papers that collected like a dozen case studies. You're not going to get universal sort of industry wide information about whether modular performs [better] and what [were the] building types and what [were the] size and what [was the] construction type.” McDaniel inferred that the construction industry, like big contracting firms, have modular data, but are not sharing or presenting the data with owners or the industry. He concluded by saying, “I think with more education, a savvy owner, and one has to suspect that hospital owners are pretty savvy, they will see the benefits” (McDaniel).

4.9.3 Experience

Experience plays a role in knowledge and implementation of modular construction. Nelson stated, “One of the things that I found is not many owner's representatives have experience with this [modular construction].” Todd suggested, “the GC [General Contractor] not knowing how to manage labor on site to accommodate. . . the scheduling and timing of mods [Modules] can be challenging [and] you need an experienced design, and construction team who's willing to take the risk and learn on a project” (Todd). Todd also suggested that an owner also plays a key role with respect to experience. He stated, “An experienced team is certainly one of them [a critical success factor to using modular construction]. An owner that is very sympathetic to the process, and is all about continuous improvement, as opposed to . . . first costs. [The owner has] got to be committed long term to make this beneficial to . . . [the owner's] build program.

Elliott also provided comments similar to Todd’s when he said, “So the decision to use modular . . . varies depending on the sophistication of the owner, and their ability to work with their industry partners. It matters that the builder, and the designer has experience with modular construction techniques, or component modular techniques” (Elliott). Furthermore, Elliot suggested that owners with experience can articulate what requirements they need and without that experience and articulation, “builders can’t provide what owner’s want” (Elliott).

Meyer and Elliott had similar thoughts. Meyer stated, “I think the primary interests by owners to consider modular construction or anything that is somehow more than the sum of its parts, is a business case that is often made to them, not by their own doing, but by the architect or the builders . . . let us face it, owners, not in this [the construction] business . . . they have to take the advice or consider the advice by the builder and the architect.” McDaniel also stated that an experienced general contractor was necessary but also stated that a key factor is buy-in.

4.9.4 Resistance or Buy-In

Familiarity with the methods of modular construction may discourage stakeholder from “buying” into using modular construction. Weber stated, “[modular construction] is something new procedurally and a lot of times, people, they want to go with the tried and true. They do not want to experiment.” With respect to a designers buy-in Jennings stated, “we got to have architects put their stamp on stuff. They want to get on the cover of Architectural Digest or whatever and that is a limiting factor.” Weber also stated that designers are reluctant to buy-in to modular design because they are unable to express their creative skills. She went on to say that “[architects] said the same thing about CAD drawings, and then about BIM drawing too and slowly but surely they were being integrated into the design process” (Weber).

The more an owner uses modular construction the more buy-in they will have on future projects. McDaniel suggested that more owners are getting interested implementing modular construction. Meyer reasoned that the more an “owner gets into modular or offsite construction and sees the benefits of it, they can become much more supportive of it, in fact, zealots of it, and therefore make it a standard and say that's what we're going to do on all our projects going forward, if it applies.” Buy-in is related to data, success stories, or providing real world examples. Nelson stated, “[If] word gets out there [and owners are] telling each other about it and understanding the benefits . . . the more I think [modular] will take off.” Elliott stated “we as humans live off stories told by others where they were successful [and] . . . we are fearful of things that may result in failure. How many people need to hear that this went well, or how much data needs to be out there so that people start believing it went well, before they start touting that project as being mythic, or legendary, and start telling that story.”

To help with buy-in Nelson's organization educates their clients by taking field trips to the local modular manufacturer and showed the owners the modular process. She stated "the owner, the architect, the engineers . . . all looked at the product before it was decided to use prefabrication. So, getting that buy in from everyone is important" (Nelson)" Nelson suggested that the more an owner uses modular construction the less owners will have to rely on success stories or field trips to the modular plant.

4.11 Regulatory Code Compliance and Inspections

One of the questions this study sought to answer was whether there were any aspects of regulatory code compliance and permitting issues that might influence an owner to use or not use modular construction. The section presents the main findings from the interviews.

Authorities having jurisdiction (AHJs) complicate the inspection process and are reticent to permit modular construction because of state or municipal codes. When asked what barriers are associated with modular construction Todd suggested that regulatory code compliance and inspections was a big problem. According to many municipal and state regulations, authorities having jurisdiction are the only ones allowed to certify and inspect building structures. Todd stated, "It [inspections] is a challenge. The reason they [municipalities or states] do not [inspect] is [because] some of the policies and procedures written into state codes or municipal codes, suggests that inspections have to be done by the authority having jurisdiction."

Taylor had the same sentiment as Todd and said that big organizations [municipalities] are reticent to change their inspection processes. He stated that "they tend to be very fixed in their ways [and] have a very fixed process in terms of a review." Taylor talked about how smaller jurisdictions can be difficult to deal with because they typically want to see the fasteners that are connecting building components. Exacerbating this problem is the location of the modular

manufacturer. Taylor stated, “when that wall is manufactured in Phoenix or in Georgia, or in Vancouver, and it comes out [to the field] preassembled . . . how do I [the building authority] know how that wall is assembled and what the quality is that goes into it.

Often modular manufactures ship modules internationally or even intranational within the United States and this becomes a problem in the inspection process. As shown in Taylor’s comment, local building officials do not want to accept inspections completed outside their state or local municipality. Jennings also had the same line of thought as Taylor with respect to AHJs needing or wanting to see how the manufacturer assembles the product. He stated, “Internal to the construction industry, how does a Quality Control (QC) inspector who has made his living in Tennessee turnover trust, that the [Modular Manufactures’] panels that are arriving from Toronto, are built to specifications” (Jennings). Jennings suggested that quality control experts from Tennessee are not likely going to fly to Toronto to conduct an inspection. Furthermore, there appears to be some internal conflict between the construction and modular industries from his perspective. He comments about this internal conflict by saying “all of a sudden, we are going to replace a construction quality control expert with a factory quality control expert and so there is some internal conflict that that creates for us in the industry” (Jennings).

When asked about his opinion on barriers associated with modular construction Jennings stated that “the certifying and codifying community need to get caught up with . . . technology.” He goes on to say that “there are concerns over what plumbing fixtures need to look like and [what] do quick connect fire sprinklers systems [look like],” with respect to certifying and codifying (Jennings).

The author was going to write about the knowledge of regulatory code compliance and inspection in the knowledge section of this analysis. However, the author felt that keeping

knowledge tied together in this section would help emphasize what the experts in the industry are saying about code compliance and inspections as it relates to OSC.

Stanley suggested that it is important to get early buy-in from building officials and stated that organizations must address code compliance at the beginning of every project. He also indicated that you do not want to build something in the factory, button it up, and then must tear it apart once it arrives on site.

Taylor's healthcare organization does a lot of preemptive work with AHJs "to ensure that they are accepting of and have become educated around how some of those premanufactured parts and pieces are being built to quality assurance." To help with this initiative, his organization invites building authorities to the premanufacturing facilities to see the assembly process. His organization leans on their internal quality control inspectors to partner with AHJs. This allows them to "speak the same language . . . advocate on behalf of the local inspector [and] to ensure that all the needs are met" (Taylor).

Todd mentioned that some states have created their own "modular programs" which is helping with the inspection and permitting process. McDaniel stated that organizations such as "the National Building Institute, the National Institute of Building Sciences and the Offsite Construction Council are working on standardizing regulation across states and jurisdictions." Similar to what McDaniel said Todd stated, "The ICC [International Code Council] has a committee . . . they're supposed to publish in 2021, a guide for authorities having jurisdiction (AHJs) and how to actually have a review and inspect these things [modules] and make that process [inspections] work more smoothly" (Todd).

Nelson inferred that it is important to do research on the regulations and code compliance. Nelson noted how the various state codes differ and inferred the key to success is “getting everyone on board with this new [modular] methodology.” She provided an example and stated,

“each state has a little bit different [rules], as far as the jurisdiction of where you can start and stop the [plumbing] pieces that come with the prefabricated unit. So, for instance, Ohio, you can have the waist and vent riser as part of the unit. Whereas in Kentucky, that has to be stick built. So, they have had some rulings, as these are becoming more common. The state and local jurisdictions have started to do a little bit more regulation of what can be manufactured and what has to be installed by a licensed onsite tradesperson” (Nelson)

Nelson also noted that there are people working in the industry with AHJs to ensure they accept certifications from across state lines. Working with the AHJ appears to be quite challenge though. Todd stated that “[negative] stigma strongly still remains with the regulator's, the permitting and inspection people.” Todd went on to say that “I am not trying to offend the regulators [but] there's not a lot of incentive for them [regulators] to do continuing education and learn about new methods and go to conferences and . . . sit in that webinar and hear about it [modular] and try to think about it [modular]. Greer also suggested that code compliance barriers are related to older regulations. He stated building authorities have not updated some codes and regulations since 2013. He inferred that this puts inspectors in an undesirable position when it comes to permitting, specifically because they have a job to keep people safe.

4.12 Transportation

One of the questions this study sought to answer was whether there were any aspects of transportation that might influence an owner to use or not use modular construction. This section presents the main findings that the author found during the interviews.

Transportation issues can influence an owner’s decision to use or not use modular construction on a hospital project. As it relates to transportation, owners should consider project

location (such as urban or suburban), distance from the manufacturing site to project site, project site accessibility or lay down area, the type of modularity (such as panelized or volumetric), transportation regulations (such as permitting, and size and weight restrictions), local wages versus transportation costs, and other many other factors.

Todd suggested that transportation can “sometimes price the project straight out.” He was referring to the distance from the manufacturing facility to the jobsite. When he published his first book, he reported that manufacturers are saying the maximum distance from the manufacturing facility to the jobsite should be no more than a radius of 200-300 miles. This distance is related to volumetric or modular construction because “you are shipping air and that is not very cost effective” (Todd). He stated that “if I am doing flat pack modular with like, exterior enclosure panels it is pretty cost effective to ship long distance, because I am not shipping any air [and] it is very dense” (Todd).

Erickson made similar comments related to distance. He said, “If I am in an isolated area, on a tight installation, obviously, I am going to have some challenges. But if I am in a more urban area where I am closer to warehouses and factories, or, I have an old warehouse on site, and the contractor can use that as swing space, and it is already there [and] it makes a ton of sense.”

With respect to distance McDaniel had the same comments as Todd and Erickson. He stated, “the further you got to go the more regulatory schemes you got to deal with, that could matter quite a bit, especially if you are going across states [or] going internationally” (McDaniel). McDaniel also mentioned that with respect to meeting “all local transportation codes and requirements” it comes down to “preplanning” (McDaniel).

Todd suggested that construction teams must plan transportation early on because of regulations and size limitations. Todd stated, “transportation is based on weight to a certain degree

[but a] more significant factor is size [and]. . . as soon as you get to a certain width, in certain states, you trigger things like special permits, or fees, you trigger things like lead cars . . . [or I] can ship only from 1am to 4am” (Todd). Todd explained that transportation regulations can differ from state to state. He suggested that a person should plan for the most restrictive department of transportation regulations along the route. He also inferred that an architect may have to design projects based on the most restrictive transportation regulations (Todd). Todd also reasoned that these transportation regulations can have an impact on cost.

Taylor stated that transportation cost is not at the “forefront” of their decision making but considered that it was important to do things sustainably. Weber also mentioned that transportation “also plays into the environmental factors and sustainability, [the] transportation costs, and energy using transportation.” Weber went on to say that environmental factors and sustainability is something an owner might want to consider. She mentioned that the General Service Administration, a U.S. Government Agency, looks at the environmental and sustainability factors when they are deciding on modular versus stick built (Weber). According to Taylor his company tries to achieve Leadership in Energy and Environmental Design (LEED) Gold certification on their projects and has recently achieved platinum design on their projects (Taylor).

Taylor illustrated that their modular partner has factories in various locations such as the Georgia, Hawaii and even Canada. He pointed out that there is cost to distribution and site location and that his company certainly considers those costs but stated again that transportation was not a driver in making decisions. Nelson stated that transportation costs can factor in your decision to use or not use modular construction a little bit. She stated their manufacturing partner is located about twenty miles from their location and inferred that transportation costs were not a huge concern. However, she stated “if we were in a different location, I would say it would be a bigger

impact and possibly in some of our more remote regions, where the manufacturing facility is farther, it might make a bigger difference” (Nelson). Jennings looked at transportation cost from a business case point of view. He said that owners are trying to save money on their projects, and they are looking to spend any saving on updating their hospitals. Jennings stated, “if I can save \$3 million dollars, which is [enough for] the rehab of four OR [Operating Rooms] . . . [and] if the shipping of [modular] panels for 1.1 million square feet of hospital is going to cost me \$3 million, I may not choose that way” (Jennings).

Nelson suggested that project teams should consider the number of units that they will transport when they consider the use of modular construction. She said, “The more units you have, the less impact shipping has just like, all the materials have to be shipped there anyway” (Nelson). Just as Todd suggested, Nelson also noted that the size of the module has implications. For example, she stated, “we’ve thought through the [transportation issues] when working through the design to make sure that it will fit on the truck and not have to have the additional expense with oversized shipping.

Some interviewees like Taylor indicated that transportation costs are not a driver that influences an owner to use or not use modular construction; it is labor wages. He also stated that stakeholders should consider transportation costs without consider other variables. Oliver echoed Taylor’s comments by stating that there is “a lot of efficiencies with productivity and potentially cheaper labor if you are shipping to a [city that has a] high union high wage rate. He inferred that if a project is in a high wage city, it may be cheaper to the build modular components in lower wage city and then have them shipped to the project site. The assumption is that the lower wages coupled with transportation costs is less expensive than building the modular building components in a high wage city.

Related to onsite labor and installation Greer suggested that the double handling of material is a cost disadvantage to onsite construction. He inferred that by constructing modular building components offsite and then shipping them onsite for installation reduces material handling and clutter. He stated, “It's hard to quantify those costs [but] there are savings gained, for sure. (Greer)”

Chapter 5: Conclusions

Overall, this study confirmed that there are many important benefits and barriers related to modular construction. Much of the findings in this study validated the current knowledge (benefits and barriers) that surround offsite construction; especially as it relates to schedule reduction, cost savings, quality, and safety. This study confirmed that the number one reported benefit that hospital owners can achieve from using modular construction is a reduced construction schedule. McGraw Hills 2011 SmartMarket Report also concluded that “a shorter project schedule was the most commonly reported productivity benefit of prefabrication/modularization. . .” (McGraw Hill Construction 2011). Owners can achieve cost savings on projects as a result of a reduced construction schedule; however, owners are not likely to save directly on modular construction costs. The *Report of Results of the 2014 Off-Site Construction Industry Survey* validates that modular construction has historically not been a low-cost solution.

Quality and safety are important factors when considering modular construction on healthcare projects. Quality is incredibly important and can positively influence hospital owners to use modular construction. As indicated in McGraw Hill Construction 2011 SmartMarket Report, seventy percent of all respondents showed that project quality improvements were a factor driving future use of prefabrication and modularization (McGraw Hill Construction 2011). This study found that safety is important but not likely a primary influencer on an owner’s decision to use modular construction. This finding reflects the results in McGraw Hills 2011 SmartMarket Report, which indicated that only fifty-eight percent of industry experts surveyed, and who were already using OSC, reported that increased safety was a factor in driving future use of prefabrication and modularization (McGraw Hill Construction 2011).

Information discovered in this study, which appears to be a gap in knowledge, shows that the construction industry needs to place more emphasis on building codes, education, and experience with respect to modular construction. In addition, there is little knowledge in these areas; especially as it relates to modular construction and hospital projects. Overall, this study found that the construction industry needs to work to update current building codes, which will result in more adoption of modular construction on projects. This study also found that more education and experience will result in better modular knowledge and this knowledge will lead to having a better understanding of offsite construction. The following is a summary recap of the results chapter.

This study found that cost can influence owners to use modular construction. To realize the cost benefits of modular construction, owners should incorporate modular early in the planning and design phase. Hospital owners may perceive that the cost of modular construction is less expensive than stick built construction and consequently it may influence them to use modular construction. Hospital owners should be mindful about capital costs related to modular construction as this might be a barrier. The cost benefits that owners achieve by using modular construction is related to standardization and repeatability which support economies of scale and cost certainty. Standardization and repeatability support economies of scale which results in more production efficiencies and consequently can lead to schedule reduction on hospital projects. The cost of modular construction, i.e., the cost of building components, is not any less expensive than traditional construction methods. However, as more owners implement modular construction the more the price of modular construction will decline. The most important cost saving factor related to modular construction is giving time back to hospital owners to do what they do best: delivering patient care.

There are benefits and barriers to modular construction related to labor. Modular construction allows for more diversity and leads to reduced schedule and reduced costs. Modular construction can lead to reduced onsite labor, reduced labor liability, and a safer onsite working environment, which all consequently leads to reduced project costs. Some experts view modular construction as an industry disruptor that creates labor shortages and potentially creates a threat to unions, and thus healthcare owners should be cognizant of this potential issue when considering the use of modular construction.

The number one benefit that hospital owners can achieve from using modular construction is a reduced construction schedule. Hospital owners want to compress the time schedule on a hospital project. Using modular construction allows for efficiencies in the construction schedule and is related to constructing the hospital project's building components offsite in a controlled environment. It is this controlled environment that allows constructors to minimize the effects of weather delays and onsite labor conflicts. Strictly using modular construction alone does not save on the construction schedule. Overall, owners can realize a schedule reduction because they are working in two different spots at the same time. Incorporating a variety of modular components improves the schedule whereas using only bathroom pods alone may not reduce the construction schedule. Overall modular construction can improve productivity onsite and result in time and cost savings.

Hospital owners could have delays and cost implication when using modular construction. Owners should consider the use of modular construction before the design is complete; the earlier the better. Modular design takes more time than traditional stick-built construction. Weather issues, scheduling issues and regulatory and/or permitting issues can cause delays to a modular project especially if the construction team is inexperienced with a modular application.

Quality is incredibly important and can positively influence hospital owners to use modular construction. Shifting work and workers from an onsite to offsite will improve quality, specifically because workers are working in a controlled factory environment. A controlled environment facilitates better quality control especially when workers are building components at waist level in an assembly/production line versus constructing products overhead. Repetition in the factory setting leads to consistency in quality which results in less change orders or rework at the end of the construction project. Eliminating or minimizing change orders and will provide owners with time and cost savings, which could influence owners to use modular construction on their healthcare projects.

This study found that safety is important but not likely a primary influencer on an owner's decision to use modular construction. However, modular construction is safer than working onsite because working onsite is arguably more unpredictable than working offsite. There are many benefits to using modular construction because of its controlled environment. Benefits such as minimizing the number of workers working around each other, removal of ladders and/or working overhead, implementation of safety mechanisms, and workers working on building components at waist level leads to increased efficiencies and repetition. Overall, these benefits will result in less injuries and a reduction in liability costs for stakeholders.

Design could influence an owner's decision to use or not use modular construction. Overall, the study found that to realize the benefits of modular construction owners should incorporate modular early in the design phase. As discussed in the cost section, incorporating modular construction early on leads to better understanding of scope and delineation, which leads to reduced change orders and improved schedule. Hospital design with repetition and standardization is necessary when considering modular construction. Planning early allows

designers to replicate and standardize the design which leads to efficiencies not only in the design phase but in the construction phase. Overall, planning and incorporating modular design early on creates efficiencies and leads to improved schedule and cost benefits.

Authorities having jurisdiction (AHJs) can complicate the inspection process and are reticent to permit modular construction because of state or municipal codes. Often modular manufactures ship modules internationally or even intranational within the United States and this becomes a problem in the inspection process. Stakeholders need to get early buy-in from building officials and owner must address code compliance at the beginning of every project. Therefore, it is important for stakeholders to do research on the regulations and code compliance during the planning and design phase. Overall, the construction industry needs to work to update current building codes, which will result in more adoption of modular construction on projects.

Transportation issues can influence an owner's decision to use or not use modular construction on a hospital project. As it relates to transportation owners should consider project location (such as urban or suburban), distance from the manufacturing site to project site, project site accessibility or lay down area, the type of modularity (such as panelized or volumetric), transportation regulations (such as permitting, and size and weight restrictions), local wages versus transportation costs, and other many other factors.

Improving education and experience could result in better modular knowledge, which would likely lead to an increased use of offsite construction. Having a full understanding of the offsite construction will lead to less resistance and positive perceptions. Overall, the construction industry is gradually overcoming issues with negative perception; especially those related to poor quality. As more owners incorporate modular on their hospital projects the more the industry will

build positive perceptions about quality. These positive perceptions will flourish as a result of increased education and experience.

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Appendix A: Interview Tool

Part 1	General Information
1.1	Briefly, can you tell me your specific individual role in your organization?
1.2	Can you tell me a little about your overall construction experience; specifically, what kind of projects have you worked on? (example: Healthcare, Manufacturing, Education or Dormitory, Hotels, Bank, Retail, etc.)
Part 2	General Experience and Perceptions of Modular Construction
2.1	Have you ever incorporated any modular manufacturing on projects on which you have worked? (example: might include incorporating enclosable usable space such as bathroom pods, shower pods, exam rooms, patient rooms, surgical suites, and/or others)
2.2	(IF YES, then): How was modular manufacturing incorporated on those projects?
2.3	Does the organization you work for now incorporate modular construction in its healthcare projects? If so, what is the most common modular components you incorporate into your projects? (example: might include enclosable usable space such as bathroom pods, shower pods, exam rooms, patient rooms, surgical suites, and/or others) (If YES, then): How did the organization incorporate modular manufacturing on those projects? Specifically, what was your decision-making process?
2.4	In your opinion, what are the benefits of modular construction?
2.5	In your opinion, what are the barriers associated with modular construction?
2.6	In your opinion, what are the most critical success factors in a modular construction project? (contractor experience, distance from modular manufacture, design, integrating stakeholders early, using BIM, etc...)
2.7	Can you think of an example where modular construction was or was not successful? If so, please explain.
Part 3	Drivers of Modular Manufacturing
3.1	What are the key decision-making points you and your organization consider when selecting modular manufacturing for a project?
3.2	In your opinion, do you think that healthcare projects benefit from a repetitive modular design? Yes or no, please explain.
3.3	Do you believe there is a negative or positive stigma associated with modular manufacturing? Yes or no, please explain.
3.4	Why is there a positive/negative stigma associated with modular manufacturing?
3.5	Is there a reluctance from you as the owner or owner's representative to use modular manufacturing on your projects? If yes, then what is that reluctance?
Part 4	Specific Factors, Benefits and Barriers

4.1	Does/Would transportation costs factor into your decision to use or not use modular manufacturing?
4.2	Does/Would the distance from a modular manufacturer factor into your decision to use or not use modular manufacturing?
4.3	Does/Would the size of modular units, with respect to transportation limitations, factor into your decision to use or not use modular manufacturing?
4.4	Does/Would cost influence your decision to use or not use modular manufacturing? If so, please explain. (Know how much the project will cost)
4.5	Does/Would price influence your decision to use or not use modular manufacturing? If so, please explain. (The cost of the project)
4.6	Does/Would a reduced or increased time schedule affect your decision to use modular manufacturing on your project? If so, please explain.
4.7	Does/Would design flexibility have an impact on your decision to use modular manufacturing. If so, please explain.
4.8	Does/Would freezing design at an early stage impact your decision to use or not use modular manufacturing? If so, why?
4.9	Does/Would quality have an impact on your decision to use modular manufacturing. If so, please explain?
4.9.1	Does/Would safety have an impact on your decision to use modular manufacturing?
4.9.2	Does/Would contractor experience have an impact on your decision to use or not use modular manufacturing? Please explain.
4.9.3	Does/Would the lack of knowledge about procuring modular manufacturing impact your decision to use or not use modular manufacturing?
4.9.4	Have you ever decided to incorporate or not incorporate the use of modular construction after the design phase has already started?
4.9.5	Has reduced labor shortages ever influenced your use of modular construction?
4.9.6	Does the lack of or use of Building Information Modeling influence your decision to use modular manufacturing?
4.9.7	In your opinion, how can the construction industry improve incorporating more modular construction in healthcare projects?
4.9.8	Are there other issues or factors about which we have not talked?
Part 5	Conclusion
5.1	Are there any issues that my questions have raised that you want to address or tell me about?
5.2	Do you have recommendations for others that we might interview?
5.3	Do you have any questions for me?