Sustainable Workflows for Permanent Modular Wood Construction

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The University of Texas at Austin School of Architecture
Author: Brandon S. Campbell
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The MDS Committee for Brandon S. Campbell
Certifies that this is the approved version of the following MDS:

Sustainable Workflows for Permanent Modular Wood Construction

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor: __________________________
Dr. Steven Moore

Prof. Ryan Smith
Title: Sustainable workflows for permanent modular wood construction

Research scope: Research is limited to the social systems within the design and delivery process of permanent modular wood construction for multifamily residential projects.

Purpose: To help incorporate more sustainable practices into future permanent modular wood construction.

Findings: Permanent modular wood construction for commercial projects involves the design of an integrated process, including the sequencing of implementation. Greater integration between designers and implementation teams led to more sustainable production. Creating solutions that consider design within a social context can help lead the industry into sustainable production.

Value for practitioners: Using findings from qualitative data, implementation guidelines for permanent modular wood construction are hypothesized.

Keywords: sustainability, sustainable construction, sustainable workflow, permanent modular construction, prefabrication.
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### Acronyms

<table>
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<tr>
<th>ANT</th>
<th>Actor Network Theory</th>
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<tr>
<td>ATFS</td>
<td>American Tree Farm System</td>
</tr>
<tr>
<td>BIM</td>
<td>Building Information Modeling</td>
</tr>
<tr>
<td>CSA</td>
<td>Canadian Standards Association’s Sustainable Forest Management Standard</td>
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<tr>
<td>FSC</td>
<td>Forestry Stewardship Council</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, Ventilation, and Air Conditioning</td>
</tr>
<tr>
<td>MEP</td>
<td>Mechanical, Electrical, and Plumbing</td>
</tr>
<tr>
<td>PMC</td>
<td>Permanent Modular Construction</td>
</tr>
<tr>
<td>SCOT</td>
<td>Social Construction of Technology</td>
</tr>
<tr>
<td>SFI</td>
<td>Sustainable Forestry Initiative</td>
</tr>
<tr>
<td>STS</td>
<td>Science, Technology, and Society (Science and Technology Studies)</td>
</tr>
</tbody>
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1. Problem Statement:

1.1 Introduction

In 2012 the Modular Building Institute (MBI) published its annual report, which advocated the advantages of permanent modular construction (PMC), a building delivery method where a large portion of a building is prefabricated as modules in a controlled environment. Modular construction incorporates an innovative assembly process involving multiple trades to create three-dimensional space-defining units rather than two-dimensional wall assemblies. These modules are then transported and assembled at a final building site. “Permanence” refers to the intent of remaining in one location for the duration of a building’s lifecycle. Founded in 1983, the Modular Building Institute is based in Charlottesville, Virginia, and acts as an international nonprofit trade association serving the commercial modular construction industry.¹

In their 2012 report, the MBI claimed that PMC is “greener, faster, and smarter” than traditional on-site building delivery methods: PMC purportedly mitigates negative environmental impacts, such as site damage and exposure of weather-sensitive materials, and contributes to less waste in landfills; a more streamlined construction process reduces construction times; and, finally, efficiencies in productions reduce both labor and material waste.² While PMC may eventually be proven to be greener, smarter, and faster, these advantages of PMC must be considered potential benefits until supporting data are provided. Attempting to do just this, the MBI has commissioned a permanent modular construction “best practices” study, which will examine eighteen projects worldwide that have been completed using permanent modular construction (Fig. 1).

¹ Modular Building Institute, “Permanent Modular Construction 2012 Annual Report,” 2.

² Ibid., 4.
Figure 1: Permanent Modular Construction “Best Practices” Study

Dayton, OH
Chula Vista, CA
San Francisco, CA
Philadelphia, PA
San Antonio, TX
Portland, OR
New York City, NY
Vancouver, BC
Ontario, Canada
Manchester, UK
Birmingham, UK
London, UK
Stuttgart, Germany
Switzerland
Helsinki, Finland
Sweden
Japan
China
1.2 Scope

In support of the MBI’s research goals, the purpose of this study is to assess the validity of the potential benefits of PMC and to serve as a pilot for the MBI’s more expansive “best practices” study. In order to do so, the scope of investigation has been reduced to examining the design and delivery process of three North American permanent modular construction projects that were completed utilizing wood as their structural framing. Wood is typically defined as any material harvested from a tree and which relies on the long-grain axis of its annual rings for its structural strength. Laminates, such as plywood or glue laminated beams, are also considered wood when the long grain of the wood remains the principle structural element. The International Building Code identifies wood construction under the label “Type 5,” which is a general category for construction with combustible materials. This study will focus only on the design and delivery process of the three projects; post-occupancy evaluation is excluded from the scope of this study.

1.3 Inquiry

The primary goal of this study is to understand how the potential benefits of permanent modular construction, as stated in the MBI’s 2012 report, can be realized. Initially the study was guided by the question: What are the factors that lead to sustainable workflows of permanent modular wood construction for commercial buildings? A sustainable workflow can be defined as a network of human and non-human actors constituting a design and building delivery process for sustainable construction. This network of actors includes suppliers, manufacturers, architects, engineers, consultants, contractors, and owners, as well as the material resources, equipment, and products they manage.

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4 Ibid., 9.
According to Charles Kibert, “sustainable construction most comprehensively addresses the ecological, social, and economic issues of a building in the context of its community.” Additionally, sustainable construction is defined as projects that are considered to be life-enhancing, profitable, safe, and that rely on certified sustainable resources by suppliers, manufacturers, architects, engineers, consultants, contractors, and owners. The term “actor” refers to and draws upon Actor Network Theory, or ANT, which was developed by science and technology scholars Bruno Latour, Michel Callon, and John Law. According to ANT, human and non-human actors, or mediators, shape social networks by transforming, translating, distorting, and modifying meaning. Drawing upon ANT allows this study to examine the effect of non-human mediators such as codes, finances, and natural resources within the workflow.

Due to a dynamic process based on grounded theory, the focus of inquiry has evolved and transformed along with the investigation. It has been identified that emergy analysis of each project would be needed to assess the sustainability of each project. Unlike other sustainability rating systems, such as LEED (US) and BREEAM (UK), emergy analysis is “a measure of all the direct and indirect energy of the material, services, and information required to make a product or sustain a system” and accounts for environmental, social, and economic factors. Since an emergy analysis would require a team of researchers to conduct it, it has been left out of the scope of this research. This study humbly seeks to access design knowledge from those who have

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8 See methodology and methods section for further discussion.
9 Pulselli et al., “Emergy Analysis of Building Manufacturing, Maintenance and Use: Em-building Indices to Evaluate Housing Sustainability.”
firsthand experience with the workflow of permanent modular wood construction. Thus, the most fitting question at this point is this: *How can design knowledge from existing workflows of PMC contribute to the development of more sustainable practices in PMC?*

1.4 **Secondary Research Questions:**

According to Nigel Cross, design knowledge resides in people, processes, and products.\(^ {10} \) People have a unique ability not only to design but also to learn empirically from experience. Processes generally involve tactics and strategies; products include forms, materials, and finishes; and both processes and products serve as precedents containing knowledge of what they should or should not be.\(^ {11} \) This leads to secondary research questions: *How can human empirical knowledge be accessed from existing workflows of PMC? What are the lessons learned from completed processes and products of PMC?*

Other secondary questions include: What is the most dependable workflow to allow for the emergence of wood modular construction? Do the key actors of the workflows benefit socially, environmentally, and economically? Is there inequity in how actors benefit? What are the key situational, organizational, and technological barriers and opportunities in developing an integrated design process for modular construction? If key barriers and opportunities are discovered, can they help to guide the trajectory of the design and building delivery process in other situations?

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\(^ {10} \) Cross, “Design Research: A Disciplined Conversation,” 5.  
\(^ {11} \) Ibid., 6.
2. Methodology & Strategic Methods

2.1 Methodology Overview:

Because permanent modular construction relies upon the technology of prefabrication, it will be examined in the context of STS scholarship. Drawing from STS literature, prefabrication technology is not deterministic, meaning it is shaped not only by its technological functionality but also by the conflicts and agreements within the social system or workflow attached to it. This study aims to test several primary assumptions or hypotheses grounded in this idea. First, in addition to describing materials and technological methods, the technology of permanent modular wood construction can be better understood by mapping the social context and the controversies and agreements that arise from it. Second, a building is best understood by its design and delivery process within the context of its community, as opposed to formal qualities and the aesthetic of the final product. Third, analyzing controversies and agreements within the community context of PMC helps to define successful design and delivery processes. Finally, the definition of “community context” will be expanded to address the ecological, political, economic, cultural, and technological subcontexts of which it is comprised. This research will take a twofold approach in order to test these hypotheses: Part one involves empirically gathering data using a hybrid of the grounded theory approach. Part two will include a mapping of the social contexts of successful PMC buildings in order to narrate graphical hypothetical answers to the research questions.

2.2 Strategic Methods Overview:

In order to collect data for the testing of these hypotheses, a case study analysis is used as the overall strategic research method for this study. As a pilot for a larger study, the number of case studies is limited to three accessible and recently completed projects within

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12 See STS section of literature review for further discussion.
North America. The specific cases were selected based on their achievement of a LEED standard and to isolate ecological, political, economic, cultural and geographical factors unique to each social structure. In order to achieve these goals, the selected LEED-certified case studies are similar in size, height, program, and material, while having differing, distinct geographies. SmartSpace SoMa in San Francisco, CA, which earned a LEED Platinum rating, is the first case study, followed by the Modules (LEED Gold rating) at Temple Town in Philadelphia, PA, and the Athletes’ Village Lodge (LEED Silver rating) in Whistler, British Columbia (Figs. 2, 3, 4).
Figure 2: Case Study Locations

- **ATHLETES’ LODGE**
  Whistler, Canada

- **SMARTSPACE SOMA**
  San Francisco, CA

- **THE MODULES**
  Philadelphia, PA
Figure 3: Case Study Sites

Figure 4: Case Study Buildings
2.3 Data Collection

2.3.1 Data Collection Methodology

In reference to these three case studies, frames of analysis for sustainable workflows contributing to the construction of PMC buildings will be studied through a variation of the grounded theory approach. Grounded theory is a generally inductive method that deduces theory from the process of collecting, coding, and categorizing data. It is distinct from traditional research methods in that it starts with data collection rather than with a hypothesis. This study uses a hybrid approach, combining aspects of grounded theory with the testing of hypotheses. These hypotheses are based on the literature review and were developed in order to fit the methodology of the existing literature of prefab architecture. They also guide qualitative investigation in order to develop interview protocols to solicit data that will fit into the existing literature.

Methodological assumptions include a constructivist framework, which influences data collection and interpretation. Data collection in a constructivist framework values multiple viewpoints of reality in order to understand social context. Accommodating various viewpoints and results will highlight areas of controversy and agreement. According to Collins, controversies and agreements within the workflows will “reflect the growing consensus.” Guba and Lincoln refer to this as the “consensus construction,” which becomes more informed and sophisticated than any construction of a single individual. From the vantage point of a constructivist, realities are relative to local contextual experience.

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13 Charmaz, Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis, 10.
16 Guba and Lincoln, “Competing Paradigms in Qualitative Research,” 111.
17 Ibid., 110.
interpretation will avoid best practices or prescriptive results in the form of universal truths.

### 2.3.2 Data Collection Methods

Data have been gathered empirically through interviews to document these varied local contextual experiences. Using the Actor Network Theory, a list of actors constituting the workflow for each project was first identified. Actors include, but are not limited to, suppliers, manufacturers, architects, engineers, consultants, contractors, and owners of each project; significant non-human actors, such as codes and finances, were also identified. Future residents were excluded from the limited scope of this study. A literature review of project publications in newspapers and magazines was used to collect project data and develop the lists of actors, which were then verified during interviews.

Second, significant human actors to be interviewed from each workflow were identified. The four most significant human actors were determined from initial interviews beginning with the architect and/or modular designer as the initial reference point, since this research likely will be most relevant to architects or designers of workflows. Interviews were performed according to a survey protocol (appendix 1). A priori categories were used in the development of the survey protocol in order to coordinate with the existing methods of research for prefabricated architecture. Smith’s ongoing research on prefabricated architecture utilizes Tornatzky and Fleisher’s three factors of technological innovation, consisting of environmental, organizational, and technological factors, which are diagrammed below (Fig. 5).

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18 See ANT section of literature review for further discussion.


20 Tornatzky and Fleischer, The Processes of Technological Innovation, 153.
Next, a total of twelve interviews, four for each case study, were conducted over the course of ten weeks. Two of the interviews were conducted in person and the remaining ten were conducted via telephone.

Figure 5: Factors of Technological Innovation by Tornatzky & Fleischer
Finally, interviews were transcribed and coded. Using grounded theory, *a priori* codes were disregarded to avoid limiting the potential creation of new categories, which could result if data were simply extruded through existing categories. Hyper Research was used as a digital tool for coding and categorization. The method for coding is outlined in appendix 2.

### 2.4 Social Context Mapping

#### 2.4.1 Mapping Methodology

In addition to the gathering of empirical data via face-to-face and telephone interviews, social context mapping was also used as a primary means of testing the hypotheses of this study. The methodology for mapping social context is based on the assumptions of the mapping controversy literature. According to Albena Yaneva, “architecture is a collective action. . . . Mapping controversies in architecture grasps architecture as simultaneously technical and social . . . avoiding architectural theory that uses philosophical decors to describe technological feats.” Based on these points of view, this study assumes that if data in the form of agreements and controversies are accessible through the use of digital media (i.e., the Web), it can help the technology of PMC incorporate more sustainable practices. Mapping illustrates patterns of agreements and patterns of conflict in an accessible, interactive platform. Design skills can be used to visualize not only an object but a controversy that is “a complex ecology of connections of an architectural, cultural, economic, and political nature.” Agreements and controversies between actors obtained from interviews act as the unit of measurement (data) to critically examine the factors that lead to successful sustainable workflows for PMC. Emerging agreements and controversies are used as frames of interpretation for categorization.

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21 See mapping controversies section of literature review, section 3.6, for further discussion.


23 Ibid., 68.
2.4.2 Mapping Methods

Regarding the mapping of controversies, Tommaso Venturini claims that “in the exploration and visualization of collective debate, the use of original research techniques is not only admitted, but encouraged. In particular, the cartography of controversies turns its expectations towards digital methods.”24 Again, drawing from the literature of mapping controversies, this study utilized a mapping controversy website as the strategic method,25 i.e., Web-based interactive charts were utilized for data collection and visualization. The content of the website follows guidelines outlined by Albena Yaneva in Figure 6.26 The website for this study is located at http://modulartimber.com.

25 Yaneva, Mapping Controversies in Architecture, 74.
26 Ibid., 74–79.

2.5 Anticipated findings and synthesis:

Based upon the STS theories outlined previously, it is assumed that the technological innovation of permanent modular wood construction is embedded in a context of ecological, geographical, political, economic, cultural, and technological subcontexts. Its success is dependent upon relationships between multiple actors within the workflow. The mapping of social contexts of completed PMC buildings, as well as making relevant data available through digital media, can improve the sustainability of future PMC buildings. Ideally, patterns of agreement and controversy will emerge through case study comparisons in order to develop grounded theoretical answers to the research questions previously posed.
Figure 6: Controversy Website Diagram – See http://modulartimber.com
Figure 7: A priori diagram of workflow
Dots represent possible patterns of controversy and agreements
3. Literature Review

3.1 Introduction

Existing academic literatures serve as valuable resources that can expose potential controversies that may arise within prefabricated building. Contemporary architecture is already a highly industrialized process that blurs traditional lines between site-built and prefabricated architecture. Doors and windows were the first commonly prefabricated architectural elements; now wall systems are becoming widely accepted by society as industrialized components of architecture. Thus, prefabricated architecture is simply a more fully realized union between architecture and industry; it is not a revolutionary method, as the logical momentum and evolution of industrialized architecture would be toward the prefabrication of entire rooms. Following this would be architectural components at the scale of multiple attached rooms referred to as “prefab” or “modular.” However, if architects perceive prefab as a threat to their authorship, or if labor unions fear it will take away their jobs, it will fail to gain momentum. These are just a few examples of the many potential conflicts that may reside in the social fabric on which this technology depends. Prefab technology is not only shaped by its technological functionality but also by the conflicts within the social system attached to it.

In order to understand how the technology of prefab architecture might gain more momentum, one must also carefully examine the social system in which it is embedded. Although inevitably more complex, this is a worthy pursuit when presented with the potential benefits of a prefabricated or off-site delivery process, which includes life-enhancing, profitable, safe, and equitable practices. Prefabricated wood construction is a recent development in the progression of industrialized building delivery. The basic idea, according to ZETA Communities, is to utilize the predominant skill set of

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construction labor in North America—Type V wood framing—within a factory setting. With this method, the use of renewable and recyclable materials can be added to the list of potential benefits.

Three recent projects have been completed in North America utilizing this delivery method, which provides an opportunity to critically examine and compare three unique social contexts of prefabricated wood construction.

One primary assumption or hypothesis, based on various literatures, is used as the framework to analyze and compare each workflow: that is, a building is defined by its design and delivery process within the context of its community. In addition to describing materials and technological methods, the technology of permanent modular wood construction can be better understood by mapping the social context and the controversies and agreements that arise from it. The literatures reviewed as the basis for this assumption include prefabricated architecture, Science and Technology Studies (STS), the Social Construction of Technology (SCOT), sustainable construction, Actor Network Theory (ANT), and, finally, controversy mapping.

3.2 Overview

A diagram of the literature review and the following paragraphs provide a brief overview outlining the relationships of these literatures (Fig. 1). Starting with the existing literature of prefabricated architecture, discussions of technology immediately lead one to pose the question: What is technology? In order to answer this, Science and Technology Studies is first reviewed. STS coalesced in the 1980s, leading to the theory of the Social Construction of Technology. The proponents of SCOT argue that it is not technology that shapes society but rather that society and technology co-construct each other, a main tenet being that society and technology are inseparable. In other words, technology is meaningless
without also considering the social forces shaping the design, fabrication, and use of a technology.

A similar theoretical trend in the literature of sustainability emerged concurrently. In 1987, the Brundtland Commission proposed that the human act of development was inextricably linked with the environment. This theoretical standpoint challenged the idea that nature existed apart from human development and paralleled the STS community’s own challenge to the belief that society existed separately from technological development. Upon reviewing the literature of sustainable construction, it is evident that the connection between the human act of development and environment has not only been addressed but embraced. In fact, there has been abundant research and development in these areas, which has led to an evolution in the way in which we design and build, the majority of which focuses on energy performance and other innovative practices to reconnect development and environment.

Much of this existing research that attempts to reconnect development and the environment has taken place from the theoretical position that society still resides outside the realm of technological development. Actor Network Theory emerged from the STS community as a methodology to specifically address this disconnection. ANT methods examine the world from the viewpoint that society, nature, and technology must all be considered as actors that influence technology and development. Controversy mapping is the most recent methodology to stem from ANT with the intent to reconnect the social and technological elements. Recently it has been applied to research in architectural design in order to understand the social influence on design by mapping controversies that occur within the social context. These literatures illustrate how permanent modular wood construction can be better

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understood by mapping the social context and the controversies that arise within it.
Figure 8: Literature Review Diagram
3.3 Prefab Architecture

Of the four literatures that will be considered, prefab literature answers three basic but important questions for this research: What? Why? How? These major themes of prefab architecture are summarized in the most recent publication by Ryan Smith, *Prefab Architecture: A Guide to Modular Design and Construction*. Other significant works referenced from the literature of prefabricated architecture are *Home Delivery: Fabricating the Modern Dwelling*; *Prefab Prototypes: Site-Specific Design for Offsite Construction*; *Building Systems: Design, Technology, and Society*; *Prefab Green*; *Prefab*; and *Jean Prouve: Prefabrication: Structures and Elements*.

What is prefab architecture? The literature defines prefab architecture as a union between architecture and industry. In *Home Delivery*, Bergdoll illustrates the historical development of industrialized architecture, differentiating it from prefab. Although contemporary architecture is already highly industrialized, prefab architecture combines the detail and aesthetics of architecture with standardized production methods on a much larger scale. Doors and windows were among the first industrialized architectural units to be socially accepted; now the same is true of industrial wall systems. Prefabricated architecture thus can be viewed as the next logical step in this progression.

Why prefab architecture? After review of Bergdoll’s work tracing the historical trajectory, it is evident that prefab architecture is gaining momentum. We can begin to understand the reason for this momentum through Smith and Kaufmann’s discussions of the benefits of a prefabricated delivery process. As previously mentioned, some of these benefits include life-enhancing, profitable, safe, and equitable practices. In order to realize the potential benefits, Mark and Peter

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31 Ibid., 218; Kaufman and Remick, *Prefab Green*. 
Anderson call for an incremental transition from site-based practice accompanied by “a deeper analysis and understanding of the social and economic forces outside of design and mechanics.” But according to Blismas, N & Wakefield, the social benefits have not yet been well researched. At this point it is clear that there is a gap in the literature, and the relationship between prefab architecture and the social forces that influence it requires further study.

How then should prefab architecture be approached? Findings from the literature suggest that prefab architecture should be designed from a production standpoint rather than from the viewpoint of an artist creating a unique work. Additionally, it is argued that prefab architecture should be viewed as context dependent, which opposes the modern ideals of context independence upon which prefabrication is founded. Prefabrication also undermines the ideals of “the architects of genius,” who feel that aesthetic merit should be the primary focus of architecture. Thus, combining what would seem to be two contradictory concepts requires a paradigm shift. The context of prefab must therefore address its context with the same level of concern as it does its technical and aesthetic agendas. “Context” for prefab architecture includes location, labor, and clients, to name a few variables. Smith posits that prefab architecture is about the design and development of a technology. In other words, prefab architecture needs to equally address all issues relating to technology, championing a collaborative environment over aesthetic prowess.

In summary, prefab architecture is the union of architecture, industry, and context and is ultimately

32 Blismas and Wakefield, “Engineering Sustainable Solutions Through Off-site Manufacture.”
34 Ibid., 3; Bergdoll and Christensen, Home Delivery: Fabricating the Modern Dwelling.
37 Ibid., 44.
about the design of a technology. Therefore, Science and Technology Studies and the Social Construction of Technology are the next logical literatures to review in order to gain an understanding of technology from a sociological perspective. For the purposes of this study, I argue that prefab architecture itself is a technology.

### 3.4 STS & SCOT: What is Technology?

Prefab architecture is a technology that requires collaboration and attention to context. STS and SCOT provide an understanding of technology from a sociological perspective, which illustrates why collaboration and context are so vital to the implementation of this technology. Science and Technology Studies coalesced in the 1980s, leading to the theory of the Social Construction of Technology. The key works from these literatures are *The Social Shaping of Technology* and *The Social Construction of Technological Systems*. SCOT argues that it is not technology that shapes society (technological determinism) but rather society that shapes technology (social determinism), and that both are inseparable. In other words, technology is meaningless without also considering the social forces shaping the design, fabrication, and use of a technology. A spectrum of viewpoints between social determinism and technological determinism exists within the field of STS. However, the commonality between them all is the understanding that the material world is shaped by varying degrees of social forces.

STS is founded upon a constructivist paradigm. Theoretically, this means that multiple and varied interpretations of reality are possible. This stands in stark contrast to positivism, which is the theoretical paradigm found within the hard sciences. Positivism attempts to create homogenous environments where the impact of a single variable can be studied at a given time, in pursuit of universal truths and laws. However, this perspective fails to account for the dynamic relationships

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39 Ibid., 24.
found within our social and technological systems. Constructivism, on the other hand, opens the door to opposing viewpoints and allows for the inclusion of all potential variables in the pursuit of site-specific meaning.\(^{40}\)

Due to a constructivist foundation and an unwillingness to accept universal rules, advocates of STS claim that technological innovation is embedded in a context of society, politics, geography, and culture. Therefore, in addition to describing materials and technological methods, technology can be better understood from examination within its social context. According to Collins, STS also focuses on the examination of social controversy, and he believes that highlighting controversy will also reflect the growing consensus.\(^{41}\) In other words, it is the controversy surrounding a technology that shapes its innovation. As such, prefab architecture is a new technology currently being shaped by its controversies. According to STS these controversies will reflect the growing consensus of relevant social groups. Pinch and Bijker posit that relevant social groups consist of “institutions and organizations, as well as organized or unorganized groups of individuals” who share similar understanding of a specific artifact.\(^{42}\) Since technological artifacts have different meanings and interpretations for various groups, the needs of each group in relation to an artifact also vary. If their needs remain unknown, they cannot be met. If they are not met, prefab architecture is destined to fail. This theoretical viewpoint provides the methodological framework to understand why the prefab architecture literature asserts the essentiality of a collaborative environment.

Advocates of STS also address the opposing viewpoint to collaboration: sole authorship and its detrimental effects. If prefab architecture valued artistic

\(^{40}\) Guba and Lincoln, “Competing Paradigms in Qualitative Research.”

\(^{42}\) Ibid., 30.
invention, sole authorship, and an end product, then the society, politics, geography, and culture attached to it would be, metaphorically speaking, taped up in a box, put on a shelf, and ignored. Bruno Latour refers to this phenomenon as a “black box,” the point at which a technology becomes so complex that it is only defined only by its inputs and outputs.\(^43\) The technology of prefab architecture would be reduced to a black box if it only focused on the input of design and the output of a building. If this were the case, it would risk not meeting the needs of the relevant social groups vital to the process of prefabricated architecture. If the needs of relevant social groups are not met, the growth of prefab architecture will surely be stunted for the sake of an architectural aesthetic agenda.

An architectural agenda of aesthetics and sole authorship parallels what STS scholars refer to as the fallacy of the “inspirational notion of heroic invention.” STS argues that technological innovation cannot occur through a flash of genius, as it would be ignoring a landscape of societal, political, geographical, and cultural conflicts. William Ogburn was one of the first STS scholars to refute the idea of the heroic inventor by stating that invention is inevitable and only occurs when society is ready.\(^44\) Since prefab architecture has been around for almost a century, it supports Ogburn’s argument by illustrating that society is slowly becoming ready to accept this technology as part of the status quo.

Thomas Hughes is another STS scholar who focused on breaking the myth of spontaneous invention though his analysis of Edison and the discovery of electric light. His work illustrates that technological innovation is a tedious process of modifying and transferring existing knowledge and technology into new areas of discovery.\(^45\)

For example, prefabricated architecture technology could utilize knowledge transfer from STS methodology for technological innovation. In contrast, fostering an


\(^{44}\) MacKenzie and Wajcman, The Social Shaping of Technology, 6.

\(^{45}\) Ibid., 6, 51.
architectural agenda of aesthetics and sole authorship for technological innovation is merely perpetuating this “inspirational notion of heroic invention.”

Traces of STS have begun to emerge in architectural theory. Notable works include Building Systems: Design Technology and Society by Moe & Smith, and Collaborative Practice in the Built Environment by Muir & Rance. Both seek to reinforce STS ideals of the collaborative environment of shared authorship. Primarily, these works strive to nurture the transfer of existing knowledge and technology that is specific to architecture. Secondarily, these works seek to create opportunities for collaborative design environments with regards to the built environment.

Another notable work is Sustainable Architectures: Cultures and Natures in Europe and North America, in which Guy and Moore warn that the moment in which an artifact becomes socially “stabilized” is commonly confused with the moment of “invention,” i.e., viewing something as an “invention” carries the risk of closing the lid on a black box. Guy and Moore instead call for pluralism in architectural innovation. Pluralism seeks to keep the lid of the black box open for examination of societal, political, geographical, and cultural factors for each individual intervention, since each new intervention is attached to its own unique context.

In summary, the STS literature seeks to reassemble technological innovation with its social context. This is in response to modern ideals of site independence in which technological innovation was considered to be separate from contextual factors. Architecturally, this cannot be accomplished through a lens of heroic invention or individual artistic authorship. Technological or architectural innovation requires investigation and participation from all relevant social

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46 Guy and Moore, Sustainable Architectures: Cultures and Natures in Europe and North America, 232.
groups in all unique interventions in order to reconnect it to its social context.

3.5 Sustainable Construction

Concurrent to the emergence of STS, a similar theoretical trend in the literature of sustainability was emerging. In 1987 the Brundtland Commission proposed that the human act of development was inextricably linked with the environment. It defined sustainable development as the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs.47 This perspective challenged the modern idea that nature existed outside the walls of human development. It also paralleled the STS community’s own challenge to the idea that society existed outside the walls of technological development. Both STS and sustainability developed in response to modernism that can be traced back to the philosophy of Martin Heidegger. Heidegger questioned the validity of modernism’s view of nature as a stockpile of resources to fuel industry and development for economic means.48

Since 1972, there has been an abundance of research and development that has led to an evolution in the way in which society views development. Development encompasses architecture, industry, and technological innovation. Reviewing the literature of sustainable construction, it is evident that the connection between the human act of development and environment has been, and is being, addressed. The majority of this research has focused on energy performance and other innovative practices to reconnect development and environment. This is largely due to the fact that literature on sustainable development is influenced by the Bruntland Commission’s definition of sustainability. From an STS viewpoint, however, much of the existing research to reconnect development and the environment has occurred from the theoretical standpoint that society

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48 Heidegger, “Building Dwelling Thinking.”
still exists apart from technological development. In other words, it lacks research and critical analysis to reconnect the social context with technological innovation.\textsuperscript{49}

\textit{Sustainable Construction} by Charles Kibbert is one of the most recent and comprehensive works relevant to sustainable architecture and construction. Kibbert states, “Sustainable construction most comprehensively addresses the ecological, social, and economic issues of a building in the context of its community.” This definition is further expanded upon by seven principles of sustainable construction: reduce resource consumption, reuse resources, use recyclables, protect nature, eliminate toxins, apply life-cycle costing (economics), and focus on quality. Although community context is mentioned in Kibbert’s definition, the seven principles illustrate a need to further define what community context means. This is similar to the

Anderson brothers’ assertion that a greater understanding of the influencing social forces is needed in the field of prefabricated architecture. STS methodology provides a depth of analysis and methodology that could help to bridge this gap.

3.6 Actor Network Theory: Understanding Technological Systems

Actor Network Theory emerged from the STS community as a methodology that has been used to understand technological innovation from within its social context, and was developed by STS scholars Michel Callon, Bruno Latour, and John Law.\textsuperscript{50} It is the assumption of ANT that technological systems can be better understood by mapping their relationships with human and non-human actors. ANT methods examine the world from the viewpoint that elements of society, nature, and technology are all potential actors that can

\textsuperscript{49} Latour, “Reassembling the Social—an Introduction to Actor-network-theory.”

\textsuperscript{50} Bijker, Hughes, and Pinch, \textit{The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology}, 4,23.
influence technological systems. ANT is unique in that it allows for the examination of the role of non-human actors or natural phenomena. A few examples of non-human actors in relation to prefabricated architecture include codes, finances, and natural resources. Albena Yaneva refers to these as “mediators” that can modify, translate, transform, or distort meaning within a social context. Latour suggests that society and technology influence each other in a symmetrical or equal manner, which places ANT in the middle of the spectrum between social and technological determinism. The current debate regarding ANT is that non-human actors are assumed to have a symmetrical or equal ability to influence a network as human actors.

Hughes’s theory of technological momentum challenges the assumption of symmetry in ANT. Using ANT, Hughes linked inanimate electrons with animate regulatory boards in a study of electric power systems.

He concluded that as technological systems grow larger, they become more society shaping than shaped by society. According to Hughes, “the social constructivists have a key to understanding the behavior of young systems.” Technological momentum suggests that an examination of the social structures at this point in the early development of prefab architecture would help one to better understand it and, potentially, influence its trajectory.

Controversy mapping is the most recent method grounded in the theories of ANT to understand how design is shaped by society. Methods involve the use of new digital technologies to map controversies within a social context. This is founded on Collins’s assumption from STS that highlighting controversy will also reflect the growing consensus. With social consensus as the primary focus, controversy mapping values the actual

51 Yaneva, Mapping Controversies in Architecture, 118.
53 Hughes, “Technological Momentum,” 104.
controversies more than scientific conclusions and outcomes. Since it leans towards social constructivism and is used to understand design, according to Hughes, it too could hold a key to understanding the young system of prefab architecture.

Recently Albena Yaneva has applied controversy mapping to architectural design research to gain an understanding of the social influence on design.\textsuperscript{56} Her main assumption is that no building can be defined outside of the process of its making, including the agreements and controversies it triggers.\textsuperscript{57} Through her examination of the Whitney Museum, she illustrates that the social adoption or rejection of architectural technologies and design can be better understood through mapping controversies. This theory could be applied to prefab timber architecture by arguing that its adoption or rejection can be understood through mapping the social context.

\textsuperscript{56} Yaneva, \textit{The Making of a Building: A Pragmatist Approach to Architecture}; Yaneva, \textit{Mapping Controversies in Architecture}.

\textsuperscript{57} Yaneva, \textit{Mapping Controversies in Architecture}.

3.7 Conclusion

The literatures of prefab architecture and sustainable construction both demonstrate the need for understanding the social forces responsible for their shaping. Drawing from the evolution of STS literature, there are two main assumptions or hypotheses being tested by this study. First, the technology and sustainability of prefabricated timber construction can be understood by mapping the relevant social context. And second, a building is best understood by its design and delivery process within the context of its community. In order to test these hypotheses, the definition of community context will be expanded to address the ecological, political, economic, cultural, and technological subcontexts.
4. Case Studies

4.1 Introduction

Modular wood construction incorporates off-site prefabrication with traditional site-built methods. Analysis of the case studies indicates that modular construction is not a deterministic technology but rather a sociotechnical hybrid of design, off-site implementation, and on-site implementation, as indicated by the STS viewpoint of sociotechnical systems discussed in the previous literature review. In summary, a deterministic technology bases its procedures and organization on a set of laws that are understood to be universal. Upon investigation of the case studies, it is evident that approaching prefabrication as an application of universal, prescribed laws fails to account for the complexities of the built environment. Simply put, this view of reality is ideological, but not empirical. In reality, incorporating prefabricated components leads to a more complex sociotechnical system with overlapping contexts of design and implementation.

Figure 9: Case Study Images

Smart Space SoMa – San Francisco
The Modules – Philadelphia
Athletes’ Village Lodge – Whistler, BC
Due to unique contextual characteristics that universal laws cannot address, the addition of off-site design and implementation requires an integrated process with increased coordination. Each case study utilized a process of prefabrication with its own unique design and implementation contexts, which in turn also had unique sociotechnical subcontexts. Ecological, political, economic, cultural, and geographical factors, in addition to technological features, informed and influenced the overall design and implementation process.

This narrative will trace how each of these unique subcontexts shaped each case study. Significant themes from interviews are illustrated in appendix 3. These themes have been paired with their corresponding subcontext within the narrative. The purpose of this investigation is to undermine the assumption that modular construction is primarily about sophisticated technical assemblies. Rather, it is instead primarily about the complex coordination and collaboration of actors within unique settings.

The ecological context of modular wood construction is the most appropriate starting point for case study comparisons, as it encompasses the greatest physical area of the contextual factors that will be examined. This is due to the influence of national and international policy regarding sustainable forestry, as well as independent sustainable certification organizations, upon it.
Figure 10: Context of Prefabrication
4.2 Ecological Context (Material)

4.2.1 Sustainable Forestry

When considering modular wood construction, wood as a material is, of course, a significant ecological consideration. Because of the proximity of all three projects to sustainably managed forests, wood proved to be an abundant renewable resource and, thus, a viable option for prefabricated construction. However, the manner by which the timber supply is secured for the future is critical for continued sustainable forest management, and Canada and the United States currently have two significantly different approaches.

Overall, the US and Canada contain 17.5 percent of the world forests. According to Natural Resources Canada, Canada contains 981.7 million acres, which accounts for 10 percent of the world’s forests.\(^\text{58}\) Additionally, Canada contains approximately 42 percent

of the world’s sustainably certified forests.\textsuperscript{59} In contrast, the US contains 736.7 million acres of forestland or 7.5 percent of the world’s forests.\textsuperscript{60} While the US and Canada contain comparable quantities of forestlands by area, there are significant differences found in the management of these forests. According to the USDA, 57 percent of US forests are privately owned,\textsuperscript{61} while this is true of only 7 percent of Canada’s forests.\textsuperscript{62} This has allowed for the Canadian government to more stringently control a greater percentage of its forestlands. By Canadian law, less than .02 percent of Canada’s forests is harvested annually and must be successfully regenerated.\textsuperscript{63} Strong government ownership has allowed Canada to retain 90 percent of the forested area it had before European settlement.\textsuperscript{64} In contrast the US has retained only about 73 percent of its forested area during this same period of time.\textsuperscript{65} Securing the timber supply is critical in order for it to remain a viable sustainable building material. Sustainable forestry initiatives provide not only specifications for certified wood and forest management but also guidelines that support social welfare among its labor force.\textsuperscript{66}

Currently, four organizations for the certification of sustainable forestry exist in North America. The Forestry Stewardship Council (FSC), which provides certifications internationally, is the largest and most widely recognized of the four and, at this time, is the only

\begin{itemize}
\item \textsuperscript{59} Natural Resources Canada, “Important Facts on Canada’s Natural Resources: Forests.”
\item \textsuperscript{60} EPA, “Forestry: Facts and Figures.”
\item \textsuperscript{61} USDA Forest Service, “Forest Legacy Program.”
\item \textsuperscript{62} Natural Resources Canada, “Important Facts on Canada’s Natural Resources: Forests.”
\item \textsuperscript{63} Natural Resources Canada, “The State of Canada’s Forests Annual Report,” 9.
\item \textsuperscript{64} Canadian Council of Forest Ministries, “Sustainable Forest Management Policies in Canada,” 1.
\item \textsuperscript{65} Oswalt, Thompson, and Smith, “U.S. Forest Resource Facts and Historical Trends,” 4. Note: 73% was calculated using the data: 1,037 million acres of forest (46% of total US land area) in 1630 compared with 754 million acres of forest (34 percent of the total land area) that remaining in 2007.
\item \textsuperscript{66} McDermott and Cashore, “Assessing USGBC’s Forest Certification Policy Options for Forest Certification and the Use of Wood and Other Biobased Materials: A Summary Report Prepared by the Yale Program on Forest Policy and Governance.”
\end{itemize}
organization recognized by LEED. However, the current
debate guided by McDermott and Cashore at Yale
suggests that LEED will develop a USGBC Forest
Certification Benchmark. This benchmark would
provide the option for all certifying organizations to meet
the criteria established by LEED and thus be recognized
for LEED credit. The Sustainable Forestry Initiative (SFI)
is an industry promoted code intended to subvert the
more sustainable standard created by FSC. SFI provides
certification within both Canada and the United States,
whereas the Canadian Standards Association’s
Sustainable Forest Management Standard (CSA) and the
American Tree Farm System or ATFS is only applicable to
Canada and the US respectively. The ostensibly
fragmented nature of these certification boards
illustrates the need for response to varying contexts and
geographical and political scales rather than the rote
application of a single universal standard.

Modular wood construction allowed for the
feasible specification of certified wood documented by
the SmartSpace SoMa project. One of the priorities of the
this project was to make sustainable materials more
accessible. ZETA Communities, the designers and
builders of SmartSpace SoMa, believes that modular
wood construction allows for efficient use of materials
that can offset the costs of certified lumber. Site-built
construction companies typically overestimate timber
needs by 20 percent to account for the inability to order it
in custom lengths and to account for field error and
weather-damaged material, factors that all contribute to
higher total material costs. Of the three case studies,
SmartSpace SoMa was the only project to incorporate
certified wood into its design. The incorporation of 50
percent FSC-certified lumber illustrates that factory
production allowed them to avoid practices that result in
higher material waste, thus allowing them to invest in

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67 USGBC, “Revised Requirements for Documenting the Use of FSC
Certified Wood in LEED,” 1.
68 USGBC, “USGBC Forest Certification Benchmark DRAFT for 4th
Public Comment.”
sustainably certified material that comes with a higher initial cost. Additionally, scrap wood was organized and stored by length for use as blocking material in future projects. This framing process is illustrated by a sequence of time-lapse photos of factory production at ZETA Communities in Figure 13.

<table>
<thead>
<tr>
<th>Minimization of Timber Waste</th>
<th>+</th>
<th>Additional Cost for Certified Timber</th>
<th>=</th>
<th>Cost for Non-Certified Timber on Site-Built Projects</th>
</tr>
</thead>
</table>

Figure 13: ZETA Communities’ Equation for Accessible Certified Materials
Figure 14: ZETA Communities’ Factory Production
4.2.2 Other Benefits of Modular Wood Construction

ZETA Communities, the modular builders of SmartSpace SoMa, and Britco, the modular builder of the Athletes’ Village Lodge can attest to the flexibility of wood in modular construction. ZETA Communities is a startup company for modular construction, while Britco has several decades of experience. From ZETA Communities’ viewpoint, modular wood construction works well for trials and experimentation in the development of their business. They find that it is easily modified on-site in the event that adjustments are needed for MEP connections. Britco also attests to the flexibility of wood construction, which is demonstrated through their methods of experimentation with factory assembly. Since each project is unique, it requires testing for specific assemblies. Each project requires two or three test modules to establish sequencing, and wood allows for ease of modification until sequencing has been determined. Furthermore, experimentation in the factory leads to error reduction in assembly. Wood construction is also a common method of building, thus many builders are already familiar with the applicable construction techniques, and skilled labor is widely available in all three regions.

4.2.3 Limitations of Modular Wood Construction

While the benefits of wood construction are substantial, it is not without its limitations. Wood has inherent material imperfections, such as knots, checks, twists, and bends. Factory tolerances for modular wood construction are limited to fractions of inches, and, therefore, material imperfections do not compromise the structural integrity of the assembly. However, in these case studies, material imperfections primarily contributed to issues with finishes, specifically in the application of interior wallboards and flooring. In order to

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prevent later rework in the field, Britco has learned over time to limit the finish work done in the factory, involving patching cracks and fixing alignment issues—issues which are all compounded during transport.

Equinox, the general contractor in Philadelphia associated with the third case study, confirmed Britco’s assessment and found corridors specifically to be prone to this issue. They were not troubled with many issues in the interior of the modules; however, because of the problems encountered in the Modules, they waited to install the wallboard on-site in their next project. Although a few floor joists were found to be slightly out of alignment in the SmartSpace SoMa project, there were no structural issues and only minor misalignments in finish floor heights where the modules connected (again, typically in corridors). This suggests that floor finishes, as well as wall finishes in corridors, should be installed on-site. Other limitations of modular wood construction include constructing sloped roofs, susceptibility to moisture, and seismic considerations. These are all primarily site-specific issues that will be discussed in the following section on geographical context.
4.3 Geographical Context
(Space/Location)

4.3.1 Shipping Routes

Examining the shipping routes within each of the three case studies emphasizes the fact that there are two different implementation teams in two different cities for the process of permanent modular construction, which stands in contrast to traditional site-built methods. Sacramento is the location of the modular factory for the SmartSpace SoMa project in San Francisco. The shipping route for this project is illustrated in Figure 15. The general contractor for SmartSpace SoMa elected to ship the modules around San Francisco Bay in order to avoid the risk of potential delays going over bridges. There was nothing prohibiting the modules from being transported across the bridges, but nor were there precedents proving that they could be shipped along this route. In the end, schedule and budget were the drivers for the decision to take the most reliable route—the one that did not include a major bridge.

Staying on schedule was critical for staying on budget, particularly because the space for staging modules and time-based fees for crane usages were extremely costly. Overtime costs for labor were minimal in comparison; therefore, the modules were delivered at 4 am, and the crew worked into the evening darkness for four long days to minimize construction costs.

Harrisburg, PA, was the factory location for The Modules project in Philadelphia. Shipping from Harrisburg to Philadelphia did not require as much navigational strategy as San Francisco, however timing issues were just as important. Renting land to stage the modules and the cost of crane rentals were again the main drivers of schedule for shipping, staging, and stacking of the modules.

Langley, British Columbia, just outside of Vancouver, was the factory location for the Athletes’ Village Lodge in Whistler. In this case, the modules were
shipped from an urban to a rural location. Land for staging was ample and relieved the staging schedule from the pressures created by land rental prices, as was the case in Philadelphia and San Francisco. However, crane rentals still proved to be costly, which accelerated the stacking schedules.
Figure 15: Module Shipping Route for SmartSpace SoMa in San Francisco, CA
Figure 16: Module Shipping Route for The Modules in Philadelphia, PA
Figure 17: Module Shipping Route for the Athletes' Village Lodge in Whistler, BC
4.3.2 Local Context / Craning

Not only were shipping routes influenced by the unique geographical contexts of each project, craning costs and feasibility also varied. Harriet Street in the SoMa district of San Francisco was the densest site of the three. Due to the density of the surrounding neighborhood, they were required to evacuate the adjoining apartment complex during the four days of craning modules over it. For this reason they were also required to use expensive steel strapping, as opposed to steel cables. The steel straps were then cut off and had to remain in place, as they do not slide out in the same manner that steel cables do. The contractor, clearly frustrated, remembered exactly how many steel straps were used on each module and how much they cost, particularly since it was an unexpected cost. There were eight straps at $75 each for sixteen modules. The cost of the straps totaled approximately $9,600, which is prohibitively expensive for a project with one hundred units. North Philadelphia, which was slightly less dense, allowed for the use of cables—which can be reused—in setting the modules.

While there was ample space for shipping, staging, and craning of the modules at the site of the Athletes’ Village Lodge, they nevertheless had their own site-specific issues. The project site was located on a former landfill, requiring unexpected costs for methane gas mitigation. Additionally, extreme snow loads required the roofs to be sloped. Framing of the sloped roofs was intentionally done on-site and proved to be the most difficult challenge in the Whistler project. Framing on top of an enclosed module also proved to be unusually difficult. Typically framers have access to the floor below when working, but in this case they were limited to work from the deck of the enclosed module below. Additionally, a large snowfall, which occurred prior to completion of the roof framing and before the connection was sealed, resulted in moisture damage to the interior finishes.
Figure 18: SmartSpace SoMa project location at Harriet Street
Figure 19: The Modules Project Location
Figure 20: Craning with Steel Straps in San Francisco (Left)
Craning with Steel Cable in Philadelphia (Right)
Figure 21: The Athletes’ Village Lodge Project Location in Whistler, BC
Figure 22: The Athletes’ Village Lodge Roof Site Framing
4.3.3 Seismic Concerns

The geographical contexts of the San Francisco and Whistler projects required additional consideration of seismic loads, which in turn required additional coordination in implementation of these projects. San Francisco is located near the San Andreas Fault, and Whistler near the Queen Charlotte Fault. Ground movement caused by earthquakes requires additional reinforcement against lateral loads, and building codes reflect this phenomenon, requiring buildings to be designed and constructed to resist seismic forces based on local anticipated earthquake acceleration as outlined in the International Building Code.⁷⁰

Attaching the factory-produced modules to the on-site fabricated foundation in the seismic zones was a significant challenge. In San Francisco, Simpson ATS rods were used to dampen seismic forces (Fig. 23). The general contractor noted that they were both expensive

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and challenging to install. In Whistler, the modular builder and contractor, Britco, who has done multiple modular wood projects, relies on traditional metal strapping to perform the same function. They believe that simplification and practicality is essential for the evolution of modular construction.

The primary difference between the two systems involves installation. Metal strapping extends from the site-built foundation and can be simply attached to the exterior of the wood modules. ATS rods extend from the foundation and pierce the factory-built wood framing. This supports one of the major findings of the study, which is that complicated assemblies require more on-site coordination and collaboration.
4.4 Political Context:

(Codes, Permits, & Labor Unions)

The political context of any technology must also be considered when evaluating its success of implementation, and cross-linked polyethylene flexible plumbing, commonly known by the brand name PEX, illustrates one of the most significant contemporary political issues in modular construction. This technology can relieve coordination pressures imposed by rigid copper or PVC plumbing. It is widely accepted in most state building codes, including California’s; however, it has not been approved for San Francisco’s local building codes.\(^1\) This is due to the fact that labor unions, who have significant influence upon the adoption of building codes in San Francisco, consider it a “labor saving device,” revealing an ongoing debate regarding the protection of skilled tradesmen versus the use of modular efficiencies as “labor saving devices.” Modular construction itself could be viewed as a labor saving device in order to achieve economic feasibility, but similar to PEX, this perspective would be an oversimplification. Multiple contextual factors, which will be examined in the next section, must be considered before economic feasibility can be determined.

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\(^{1}\) Robert P. Mader, “California Approves PEX for Plumbing — Again,” 1.
4.5 Economic Context: Feasibility of Site and Factory

4.5.1 Introduction

Economic feasibility is a significant factor influencing the viability of permanent modular wood construction. Figure 25 provides a comparative overview of the size, construction costs, number of modules, design and construction times, project scales, and module layouts. However, these variables are not necessarily easily compared, since each case study has its own unique economic factors. For example, the team working on The Modules project in Philadelphia was able to produce the greatest square footage with the smallest budget per square foot. This was primarily due to North Philadelphia’s unique economic factors. Economic comparisons for modular construction must account for the unique contexts of both site and factory implementation. The main indicators for economic comparison between the case studies include real estate values, construction budget, and construction wages.

4.5.2 Real Estate Values

Real estate values are significant in determining construction budgets in several ways. The amount of money banks are willing to loan is based on the estimated value of the completed project. In Whistler, BC, and the SoMa district of San Francisco, real estate costs are extremely high, therefore banks are also willing to loan more in these regions. In contrast, real estate costs in North Philadelphia are relatively low, so construction loans are lower. Additionally, real estate values determine the amount of profit that the developer can make on the investment through sales or rentals. Construction budgets, therefore, must also reflect a balance between potential profitability and projected construction loans.
<table>
<thead>
<tr>
<th>Location</th>
<th>Square Footage</th>
<th>Cost per Sq Ft</th>
<th>Modules</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>SmartSpace SoMa</td>
<td>10,000 Sq Ft</td>
<td>$276/ Sq Ft</td>
<td>16 Modules</td>
<td>7 Months</td>
</tr>
<tr>
<td>The Modules</td>
<td>80,000 Sq Ft</td>
<td>$137/ Sq Ft</td>
<td>89 Modules</td>
<td>12 Months</td>
</tr>
<tr>
<td>Athletes’ Village Lodge</td>
<td>70,000 Sq Ft</td>
<td>$328/ Sq Ft</td>
<td>59 Modules</td>
<td>18 Months</td>
</tr>
</tbody>
</table>

*Figure 25: Comparative overview of case studies*
4.5.3 Construction Wages

Construction wages influence the financial feasibility of new construction as well as the livability of construction workers. On-site construction wages are, on average, approximately 50 percent higher than those of factory labor, largely due to the fact that on-site workers are required to be members of a labor union. Although there are no fixed union labor wages, according to the general contractors in San Francisco and Philadelphia, wages are based largely on prevailing rates within the respective geographic areas. Construction labor unions do not consider factory construction workers to be members of their unions; therefore they are neither privileged with union wages nor prohibited from working for less. Although Canada has labor unions, there were no union workers on the project—according to the general contractor of the Whistler project—nor were they influential in determining wages since wages in Canada are approximately the same for on-site workers as they are for factory workers.

4.5.4 Comparing Real Estate Costs with Construction Wages

Comparing local real estate prices with construction wages further determines the measure of livability for construction workers. For modular construction, this comparison must include the site-built context and factory context. All case studies have modular factories that are situated in cities with real estate prices lower than those of their corresponding site locations. Combined with their ability to provide secure, safe, and reliable places to work, factories can provide jobs that would otherwise be unavailable to the factory worker or the union laborer on-site.
Figure 26: Economic Comparison of Site-Built Context vs. Corresponding Factory Context
Comparing real estate prices with construction budgets illustrates their mutually dependent relationship. The notable comparison is that the construction budget per square foot and real estate values in North Philadelphia are significantly lower than those in either San Francisco or Whistler. This challenge made modular construction the only viable delivery method for the context. According to the developer of The Modules project in Philadelphia, site-built construction alone would have made the project financially unfeasible. Modular construction allowed for the construction budget to total approximately $11 million compared to the projected site-built construction cost of $13.2 million. The $2.2 million reduction in total cost is due in large to the reduced employment costs of factory workers. Labor costs for union workers to build the project on-site would have been an estimated 50 percent more.

Although construction prices are much higher in Whistler and San Francisco, the market value, based on local property values, absorbed some of the costs. The developers could receive higher compensation due to higher appraisals of the final building. The project drivers for the San Francisco and Whistler projects were less about construction prices than they were in the North Philadelphia project. Instead, in Whistler they were mostly about access to skilled labor. Skilled labor was in high demand during the time of construction due to a simultaneous increased volume of construction projects occurring in preparation for the 2010 Olympics. The location of the modular factory near Vancouver, BC, allowed for greater access to skilled labor to produce the modules. In San Francisco the project drivers for modular construction were more about geography, quality, and an investment in new construction methods.
Real Estate Values

Construction Budgets

*Figure 27: Economic Comparison of Real Estate Prices vs. Construction Budgets*
4.5.6 A New Perspective on Modular and Labor Unions

In San Francisco the modular builder for SmartSpace SoMa, ZETA Communities, builds their business model upon the concept that many projects are constrained in the same ways as that of the Philadelphia project, i.e., the project is not financially feasible unless there is a means to minimize construction costs. Labor unions would argue that wages are not the appropriate place to make cuts; however, there are several other factors to consider. Modular projects still provide work for labor union workers; there are also many projects that would not be feasible without a modular component; and a large portion of modular construction still requires on-site work.

ZETA Communities is in the process of finding ways to coordinate and collaborate with labor unions. This is not a purely altruistic gesture, as they understand the value and quality of craft that they receive from labor unions. The contractor of the SmartSpace SoMa project admitted to a preference in union labor professionals for the site-built portion of construction, due to the knowledge, quality, and consistency that they bring to a project. In order to strengthen relationships with labor unions, ZETA Communities offers their factories as a training ground for union apprentices to work for factory wages while building union credentials. The future of PMC can be strongly enhanced by new methods of coordination and collaboration with unions such as this.

These ideas begin to incorporate social equity, one of the three dimensions of sustainable development, into PMC. The typical diagram used to illustrate sustainable development consists of three separate but connected rings of environment, society, and economy.72 Analysis of the case studies suggests that there are greater linkages between the three dimensions than have traditionally been indicated.

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4.6 Cultural Context (Perceptions)

In addition to the contemporary ecological, geographic, political, and economic contexts of these case studies, it is also important to consider the historical development of wood modular construction, as well as the culture that surrounds it. The cultural context of wood modular builders likely developed from the tradition of single-family construction, a theory that is supported by the modular builders themselves. Historically they have built their businesses from smaller-scale, mostly single-family projects, which can be delivered to the site almost 90 percent complete. Culturally, modular builders have become accustomed to their responsibility for a project ending once factory work is complete.

In the transition from single-family modular homes to multifamily residential projects, this hand-off approach requires more coordination and collaboration between the modular builder and the on-site construction crews. This is evident when comparing factory implementation to the site work required for the three case studies. On average, only 50 percent of the case studies were produced in the factory (Fig. 27). In the two urban case studies, SmartSpace SoMa and The Modules, greater percentages of each project were completed in the factories because of limited space to work on-site. Additionally, it was more cost effective to incorporate doors, windows, and interior finishes in the factory due to the high costs of on-site union labor. For The Modules project, maximizing the amount of work
completed in the factory was important more for financial reasons than space limitations—the latter being the case for the SmartSpace project—since the location was less dense and property values were lower. The Athletes’ Village Lodge was subject to neither excessive space restrictions nor high costs of on-site union labor. Their decision instead was based on a need for efficiency and a lack of access to skilled labor, which was difficult to find due to an unusually high quantity of construction occurring for the Olympics.

The increased need for more coordination and collaboration between site and factory implementation for larger projects is also illustrated by timelines of design and construction. What is important to note is how much longer construction continued on-site after the modules were set in place. Additionally, as the scope of work of the factory work increased, the need for coordination and collaboration also increased. A shorter construction timeline also required more coordination. Analysis of these case studies illustrates that expansion of modular construction methods into multifamily and commercial projects requires a new culture of integration, coordination, and collaboration.
Figure 29: Scope of Factory Implementation (% Modular)
Figure 30: Design and Construction Timelines
4.7 Technological Context (Roles)

4.7.1 Introduction

As with the other contextual factors discussed previously, the technological context of modular construction is primarily about the coordination and collaboration of roles. Designing systems of prefabrication requires more than determining aesthetics and material assembly: design must also designate the roles of collaborators and the degree of incorporation of prefabricated processes. Among these case studies, conflicts primarily arose in the context of site implementation. A majority of respondents spoke of the overwhelming importance of defining scopes of work and responsibility in prefabricated processes, supporting the idea that technological systems of prefabrication are also social systems. Furthermore, a prefabricated system has a significantly more complex social component than site-built systems due to the fact that prefabrication incorporates an additional set of designers.

Figure 31: Systems Coordination
The Modules - Philadelphia
and work crews who must be integrated into the design process.

The case studies demonstrate that prefabrication is a hybrid of both design and implementation, requiring a high level of integration. Prefabrication requires its own set of agreements and social contracts, unique from site-built projects, to deal with overlapping roles and shortened timelines.

Figure 31 above illustrates the major systems of coordination for multifamily PMC projects. Architects and architectural engineers coordinate with modular designers and modular engineers to design an integrated process of factory and site implementation, where all systems overlap. This coordination is illustrated in the construction sequence in Figure 31. The first image shows the site-built foundation. The second image shows the stacking of the modules on top of the foundation. Finally, the bottom image shows mechanical, electrical, and plumbing systems that overlap both site and factory work.

4.7.2 Scopes of the Workflow

Each of the three case studies organized and defined scopes of work in the design and implementation processes—as well as contractual and financial responsibilities—differently. In some cases these divisions of labor did not align, producing oversights in certain areas of design, which then resulted in implementation errors or the need for rework. Examination of the workflows illustrates that the implementation of modular construction is an extension of the design process. The manner in which roles and responsibilities are organized directly determines the effectiveness of implementation teams. In the end, the case studies that had more direct contracts with the design teams led to more successful processes of implementation.
4.7.3 SmartSpace SoMa Workflow

In the case of SmartSpace SoMa in San Francisco, the contractor commissioned the entire design staff. The reason for this type of organization was based on finances and team experience, as illustrated in Figure 32. The general contractor is a multimillion-dollar contracting company with the resources to take on the material risk, while the owner was able to financially guarantee the project with personal assets. The ability of the owner to assume financial risk, combined with the ability of the contractor to assume material risk, eased concerns of the bank when providing a construction loan. Additionally, the owner and the contractor both had evidence of successfully completed projects, resulting in an extremely reliable team. The project would have not been feasible under any other organizational structure.

The use of multiple design teams commissioned by the general contractor was uncharted territory for the entire team. Since the contractor took on the primary risk for material assemblage, they contractually made themselves the hub of design information. It was their responsibility to coordinate the implementation of the few design details that were not fully addressed in the initial design. All members viewed this process as an educational investment before taking on larger projects. The process ended with a great sense of accomplishment on the part of the members and a willingness to continue working together. The team discovered that designing for modular construction must overlap with the implementation process. Restricted timelines and overlapping implementation teams require that all members of the design and implementation teams review drawings and take partial responsibility for their completeness and feasibility. Traditional site-built methods allow for flexibility to make modifications in the field; modular construction does not. For this reason, it makes sense to chart or develop a new building culture for modular construction, where site implementation crews can be involved in the design process from the
beginning and share responsibility for the feasibility of the design.

Field resolution of the issues resulted in delays and cost overruns due to insufficient space for rework and need for redesign of some of the mechanical spaces. In the end, the project was on schedule but over budget. The implementation of MEP and HVAC systems were problematic. For example, in the preliminary design

*Figure 32: Design Workflow of SmartSpace SoMa, San Francisco*
the plumbing connections cleared the structure; however, in the field the general contractor had to orchestrate the removal of plumbing in order for installation of the structure to take place. Another instance required new installations of access panels in already-finished ceilings of modules to be installed in the corridors in order to provide access for plumbing valves and electric junction boxes for installation and maintenance. Other on-site modifications included the addition of individual utility closets, which were barely able to accommodate their respective water heaters, solar water heaters, and exhaust fans, thus compromising future serviceability. The main utility closet for the buildings’ MEP riser system was also designed with insufficient space, requiring electrical meter banks to be relocated. The resulting workflow [Fig. 31] illustrates how the contractor consolidated design information for implementation.

After the project was complete, the contractor and the modular builder agreed that the organizational structure did not allow for the various design roles to coordinate under a central point of design. Scopes of work for the design of the individual modules, the overall structural system, and the exterior finishes were clearly allocated to different design teams and executed successfully. Since all of the design work did not come from a central point, the responsibility for a realistic solution for MEP remained unaddressed until the general contractor was forced to resolve it in the field. Due to the builder’s reliance on typical site-built construction strategies where revisions can still be made in the field, agreements had not been made to review MEP documents prior to construction. Unfortunately, modular construction does not easily accommodate these types of on-site modifications, thus the coordination of information prior to implementation is imperative.
Figure 33: Design and Implementation Workflow of SmartSpace SoMa, San Francisco
4.7.4 The Modules Workflow

In the case of The Modules, the owner and the contractor were the same entity. The diagram of roles is similar to SmartSpace SoMa, where the owner/contractor commissioned a separate architect and modular builder. However, the projects differed in that the architect and modular builder each commissioned their own engineering consultants. The architect was also commissioned before the modular builder, allowing them to act as the central point of design and coordination of the building systems. With a few minor exceptions, the project was completed within the allotted budget.

Notably, the architect used conventional two-dimensional drafting methods (AutoCAD) to organize design data. This reinforces the concept that modular construction is a
technology with a relatively high social component that does not rely on three-dimensional building information modeling (BIM). Modular technology can be organized with traditional methods just as easily as with more cutting-edge digital methods. Also notable is the foresight of the owner/contractor to require that the modular builder/designer take responsibility for the on-site assembly of the modules. Similar to SmartSpace SoMa, the project experienced implementation conflicts stemming from undefined roles in the coordination between factory and on-site implementation crews.

Foresight of The Modules’ owner inspired him to experiment with contracting the modular fabricator/designer to take contractual responsibility of the set crew. Current methods include a third-party set crew to orchestrate craning and setting of the modules. The general contractor typically contracts the set crew. This contractual relationship makes the general contractor ultimately responsible for assembly of factory-produced work. For The Modules project, the modular fabricator took contractual responsibility for the delivery, storage, and setting of the modules—an agreement that proved to be successful.

The major obstacles within the workflow arose during site installation of the MEP and HVAC systems. Contractually, the general contractor served as the middleman between the designers and the MEP and HVAC crews. Unfortunately design teams drew plumbing and electrical runs in locations where it was difficult to make connections once the modules were set, and it was the general contractor who was ultimately responsible for ensuring that all connections were made. Instead he would have preferred to transfer some responsibility to task-specific implementation crews by giving them a more active role during design reviews, prior to the completion of the design process.
Figure 35: Design and Implementation Workflow of The Modules, Philadelphia
4.7.5 The Athletes’ Village Lodge Workflow

In the case of The Athletes’ Village Lodge in Whistler, the contractor and the modular builder/designer were the same entity and best describe themselves as a modular company with a general contracting branch. This method of organization allows for design and implementation data to be gathered within one central location—a structure that was reinforced by the commissioning of all social contracts, or scopes of work, under the same entity. Similar to The Modules, the majority of work was not organized using BIM but instead relied on traditional two-dimensional methods. Three-dimensional BIM modeling was reserved for MEP systems and stairways only.

Figure 36: Design Workflow of The Athletes’ Village Lodge, Whistler
Figure 37: Design and Implementation Workflow of The Athletes’ Village Lodge, Whistler
This proved to be an effective method since the project was completed both ahead of schedule and under budget—to such an extent that all members of the contractor/modular builder team were rewarded with bonuses. Although the project had great success, it was not immune to a few the site complications, which are discussed in the section on geographical context.

In Whistler, there were large successes with integration due to the previous experience of the modular manufacturer, Britco, and its method of organizing contracts under one central structure. Mechanical and plumbing systems were color coded and numbered; detailed three-dimensional drawings were also provided. BIM was implemented specifically for utility coordination, which created a detailed road map for ease of implementation. Complications were mainly due to mountain conditions of Whistler, which has been discussed previously in the section on geography.

4.7.6 Role of Building Information Modeling

As these case studies illustrate, design data must be organized under a central location to evaluate and understand the impacts and influences of all actors on workflows. Building information modeling has the potential to do just this. BIM is a technological method for digitizing collective input and can be a useful tool if there are strong social agreements surrounding the technology. This perspective is reflected in a statement made by GSA’s Charles Hardy: “BIM is 10 percent technology and 90 percent sociology.”³³ BIM was used to varying degrees for each project. SmartSpace SoMa attempted full integration of BIM; The Modules did not utilize BIM at all; and the design team for the Athletes’ Village Lodge used BIM strategically for MEP, HVAC, and circulation systems. Using BIM to organize design data in one central location is very efficient, but the social

agreements surrounding the technology are equally as important. Analysis of workflows indicates that modular construction could benefit from implementation teams being contracted for design reviews prior to completion of the design phase.
An overall comparison of workflows illustrates the comparative overlaps in design and implementation for each project. Blue areas represent design teams, and gray areas represent implementation teams.

The diagrams highlight the fact that permanent modular construction is not only about technical assemblies. Prefabrication for multifamily projects is about the design of an integrated process, which includes the sequencing of implementation. Finally, more integration between design and implementation teams leads to greater potential for sustainable production.
5. CONCLUSION:

5.1 Introduction

In conclusion, the case studies demonstrate that modular construction is not only about its technological assemblies; modular construction for multifamily projects is about the design of an integrated process, which includes the sequencing of implementation. More integration between design and implementation teams leads to greater potential for sustainable production, as does an approach that combines the disciplines of design and the social sciences.

Using the lessons gained from the qualitative data discovered from this study, a hypothesis has been generated to develop implementation guidelines for off-site construction. This hypothesis suggests how social sciences can be incorporated into the design process. The guidelines involve a three-part process that takes the shape of an extensive site analysis prior to design: The first step is for design teams to understand and evaluate contextual factors. Using this data, the second step is to determine the scope or percentage of modular construction. The third and final step is to identify roles and scopes of work through diagramming methods.

The case studies illustrate that ecological, geographical, political, economic, cultural and technological factors can have a significant influence on workflows. Initial site analysis to gain an understanding of significant site-specific factors can help determine the percentage of modular construction that is appropriate for that particular project and context. It can also help identify tasks that may arise because of unique contextual factors, in order to develop specific roles or scopes of work of the various design professionals.

The recent idea that prefabrication allows for context-independent architectural production has been demonstrated to be ideological. In contrast, my finding is that prefabrication rearranges the power relations between human and non-human actors in context-dependent projects. Understanding the unique contextual
factors of each project can allow for PMC to develop more sustainable practices.

5.2 Understanding Contextual Factors

According to Howard Davis, an “increased knowledge about the building culture might lead to the improvement of the built world.”\(^7^4\). This argument is supported by the findings of this study. The case study comparisons highlight unique social systems of production as well as their unique contextual factors. Based on these findings, I argue that there is a need for an extensive context and production analysis prior to design or selection of a delivery method due to the fact that every project has unique programs, goals, and contexts.

The case studies serve as a narrative to support this hypothesis: if an extensive context and production analysis is conducted, PMC can develop more sustainable practices. Six factors of assessment are outlined below as recommendations for a context and production analysis. The six factors, developed from the case study narrative, include ecological, geographical, political, economic, cultural, and technological factors.

5.2.1 Ecological Factors: Availability and Limitations of Wood

Several ecological considerations have been abstracted from analysis of the case studies. First, what is the local material availability, and how does it impact selection and feasibility of sustainable resources? These are important questions to ensure the future supply of materials. Second, what are the limitations of wood, and how do they affect implementation? The limitations of wood were consistent among the case studies. Understanding these limitations helps determine what work is best done in the field and what work is best done on-site. For example, the inherent imperfections of wood make it difficult to align factory-finished components on-site. Instead, it is generally preferable to implement

\(^7^4\) Davis, *The Culture of Building*, 4.
finishes located near the seams of the modules in the field. These seams most commonly occur in interior corridors and along exterior walls of modular wood buildings.

5.2.2 Geographical Site Assessment & Site-Specific Conditions

The case studies have also raised several geographical concerns. First, what are the specific soil and seismic conditions? What are the module transportation routes from the factory to the site? What are the specific site factors that will impact the implementation of modular construction? Asking these questions will reveal potential hidden project costs. The San Francisco and Philadelphia case studies demonstrated the hidden costs of shipping and craning of modules within a dense urban fabric. The San Francisco and Whistler projects also showed the financial impact of seismic conditions. The Whistler case study alone demonstrated hidden costs from methane gas mitigation within unknown soil conditions, and the need for site-specific feasibility studies.

5.2.3 Political Factors

Questions uncovered from the political context are as follows: First, what are the specific code requirements that support or hinder coordination and collaboration? Codes for flexible plumbing, as discussed previously, indicate the relevance of this question. Second, what are specific labor union agreements for the specific location? It is possible that they are irrelevant, as shown by the Whistler case study. It is also possible that avoiding union labor costs by using factory labor instead allows for a more economical means of production. It may also be possible that coordinating with unions—to whatever extent that might be—could lead to better-crafted, higher-quality projects.
5.2.4 Economic Factors

Analysis of the case studies also indicates several economic factors that must be addressed. First, how do factory locations affect project feasibility and livability for workers? In the Whistler case study, it is shown that a larger percentage of skilled labor can be accessed through factory conditions. The San Francisco and Philadelphia case studies show how factory settings can combine livable worker conditions with economical means of project delivery. Additionally, how do lending agreements impact social structures, and are these ideal for modular construction? The San Francisco case study illustrates how lending agreements can place general contractors at risk for design work.

5.2.5 Cultural Context of Modular Wood Construction

The question uncovered from the evaluation of cultural context primarily deals with the scope of work of the modular manufacturer. How can the historical single-family building traditions of the modular wood manufacturers be expanded to address the needs of multifamily projects? The Philadelphia and San Francisco projects demonstrate the need to extend the scope of work of modular manufacturers into the implementation process, which can help to ensure greater collaboration in the entirety of the process.

5.2.6 Technological Context of Modular Wood Construction

Analysis of the technological context highlights the need to address how coordination and collaboration of social systems can ensure successful implementation of mechanical assemblies. Thus, what are the specific divisions of responsibility between design and implementation professionals? All projects demonstrate the complex social systems manifest within design and implementation teams. The Whistler project demonstrates success of the simplification of technological assemblies within a complex social system,
while the San Francisco and Philadelphia projects demonstrate complications arising from the use of sophisticated mechanical assemblies in complex social systems. The analysis does not suggest the avoidance of complex mechanical systems but rather suggests the need to foster a social system that can accommodate these assemblies.

5.3 Determining the Scope/Percentage of Modular Construction

Upon completion of a thorough site analysis of ecological, geographical, political, economic, cultural and technological factors, the scope or percentage of modular construction can be closely approximated. This may include a cost–benefit analysis to select an appropriate delivery system and to avoid hidden or unexpected costs. It may also be used to determine whether modular construction is appropriate for a given situation, which can only be known after a thorough examination of site-specific contextual factors.

5.4 Identification of Roles: Connecting Flows of Information

If modular construction is determined to be appropriate, team selection and methods of coordination can be addressed. This includes the assignment of roles and the definition of scopes of work in order to prevent wasteful duplication of effort. An example of the need for this if is found in the San Francisco project where the general contractor was left to redesign appropriate spaces for MEP and HVAC systems. Assigning roles and defining scopes of work can also prevent negligent gaps in design. Both the San Francisco and Philadelphia projects suffered from these gaps, specifically within the design of their MEP and HVAC systems. Finally, the role of BIM can be addressed. Defining scopes of work can determine who is responsible for design reviews of the building model. Analysis of the case studies suggests that implementation crews should take greater contractual responsibility for approving the viability of building systems design.
6. Bibliography


This paper demonstrates the steps in the method of grounded theory. It describes the difficulties encountered in applying grounded theory. A fundamental part of the analysis method in GT is the derivation of codes, concepts and categories. The focus is on discussing grounded theory as a research method rather than the results of a case study.


This book is a compilation of essays analyzing the social trajectories of technology throughout history. Each is an guiding example for analyzing the social trajectory of modular wood construction.


Cross argues that design knowledge resides in people, processes and products. He proposes various forms of 'designerly ways of knowing', which support the paradigm of design research.

This paper investigates the complexity of the ‘social’ as an object of study. After taking a look at several different theories, an alternative approach is argued, one that argues to move beyond a traditional ontology of the social.


This chapter outlines the history of interviewing and discusses the academic uses of interviewing. The focus is on qualitative methodology. Major types of interviewing are discussed such as structured, group, and unstructured. Various elements of qualitative interviewing are also discussed, such as issues of interpretation and reporting. Finally, considerations related to ethical issues are examined.


Gadamer, in 1975, further developed the concept of Heidegger’s hermeneutic circle, leading to what is recognized as a break with previous hermeneutic traditions. While Heidegger saw the hermeneutic process as cycles of self-reference that situated our understanding in a priori prejudices, Gadamer conceptualized the hermeneutic circle as an iterative process through which a new understanding of a whole reality is developed by means of exploring the detail of existence.


This book acts as a practical guide to research specifically written for architects. Basic research issues relating theory to method and design to research are presented. Seven types of research are covered, including historical,
qualitative, correlational, experimental, simulation and modeling, logical argumentation, and case study and mixed methods.


Guba and Lincoln analyze four research paradigms: positivism, post-positivism, critical theory, and constructivism. The four paradigms are examined with regard to ontology, epistemology, and methodology. This chapter is written when constructivism was in early development as a research paradigm. Guba and Lincoln argue that realities take the form of multiple viewpoints that are socially and experientially based.


Hermeneutic Circle: Heidegger’s use of the hermeneutic circle occurs in his examination of *The Origin of the Work of Art* (1935–1936). Heidegger argues that both artists and art works can only be understood with reference to each other, and that neither can be understood apart from 'art,' which, as well, cannot be understood apart from the former two.

Hughes, Thomas P. “Technological Momentum.” *Does Technology Drive History* 101 (1994).


Latour takes the approach of a tour guide to introduce research utilizing Actor Network Theory. He describes the importance of this approach lying within the associations between actors, both human and non-human.

This essay argues for the dismissal of the static Euclidean view of buildings in favor of architecture that captures the flow of transformations.


Law asks the question how objects, artifacts, and technical practices come to be stabilized. His analysis can be used to guide analysis of the social trajectory for modular wood construction.


Ricoeur combines phenomenological description with hermeneutic interpretation.


Donald Schön characterizes design as a hermeneutic circle that is developed by means of "a conversation with the situation."


In this book, Scott analyzes failed cases of large-scale authoritarian plans in a variety of fields. Scott argues that the success of designs for social organization depends upon the recognition that local, practical knowledge is as important as formal, epistemic knowledge.


Judith N. Shklar points out the ambiguity in the meaning and function of the “circle” as a metaphor for understanding. It seems to imply a center, but it is unclear whether the interpreter him-/herself stands there, or whether, on the contrary, some “organizing principle and illuminating principle apart from him is there waiting to be discovered.”


The separation of concepts applicable to groups from those applicable to individuals is a powerful tool for eliminating the solipsism characteristic of traditional methodologies. Science becomes intrinsically a group activity, no longer a one-person game.


Woodhouse and Patton propose that STS can help identify what stands in the way of a thoughtfully designed and equitable technological civilization. They argue that this knowledge can be incorporated into design practice and scholarship.


This book explores the social complexity of architecture in the making. Yavena offers a new way of understanding architecture as practice that takes place within the interactive networks of human and non-human actors drawing on her primary investigation of architects at work at the Office for Metropolitan Architecture (OMA) of Rem Koolhaas in Rotterdam from 2001-4.


This book discusses data collection techniques, data analysis, reporting, and the issues of validity, reliability, and ethics. It reviews the nature and design of qualitative research and discusses various types of qualitative research including case studies. The book also covers the collection of qualitative data such as conducting interviews and observation.


The primary purpose of this paper is to explain the benefits and limitations of modular construction as it pertains to primarily wood-frame, multifamily housing in the United States. It attempts to educate the consumer/builder/developer about what the modular construction process entails from beginning to end.


This paper argues that reliance on design and site management are not sufficient for sustainable goals. The research posits the importance of selecting more environmentally sound designs during the project appraisal stage. This stage is found to be the best for addressing environmental matters.


Kibert Focuses on sustainable construction as it applies to commercial and institutional buildings. He covers the theory, history, state of the industry, and best practices in green building covering design, construction, materials selection and the use of natural systems for wastewater processing.
Principles of sustainable construction are developed and divided into four pillars: social, economic, biophysical and technical. A multistage framework is proposed, which requires the application of Environmental Assessment and Environmental Management Systems for construction projects.


Kieran and Timberlake present an argument for moving architecture from a linear approach to an integrated one that brings together technology, materials, and production methods. Examples from several industries that have successfully made the change to an integrated-component approach are used. These include the auto, shipbuilding, and aerospace industries to illustrate how to improve quality while saving time and money. Their argument is based on the redefinition of the roles of architects, materials scientists, process engineers, and contractors.


The MBI annual report documents growth opportunity, markets served, waste minimization, financial results, and global projections for permanent modular construction projects completed in 2011.


This study uses life-cycle assessment to quantify the environmental impacts of constructing a typical residential home by comparing modular and conventional on-site methods. The study shows that the average impacts of building a home are less for modular construction than for conventional construction.


Sheil, R. “Manufacturing the Bespoke.” [2012].

Sheil argues that the roles, methods, and capabilities within disciplines of building production are in an unprecedented state of flux. The book features essays from pioneering architects, engineers, academics and designers from around the world on new and un-built structures. It aims to contextualize and define new meanings for architectural production.


CIB’s Agenda 21 is a conceptual framework that serves as an intermediary and provides for comparison and coordination of global collaboration and coordination to specifically address sustainable development for the construction community.


This book is a guide to off-site construction, presenting the opportunities and challenges associated with designing and building with components, panels, and modules. It presents the drawbacks of site building and argues that prefabrication allows for better integration of products and processes, efficient delivery, and realizing value in project life cycles.


Utterback’s research demonstrates that the effectiveness of firms in originating, developing, and implementing technical innovations is viewed as a function of three sets of factors: the first being the characteristics of the firm’s situation; the second being internal organizational characteristics of the firm; and the last being the technological flows between the firm and its situation.
Appendix 1: Interview Survey Protocol

To verify interviewees & hierarchical relationships
- Who were the most important decision makers during design?
- Did this change during fabrication or construction?

Environmental questions
- Team questions
  - How many people in your office worked on the project?
  - Was there a formal or informal organizational structure?
  - Who had what roles during fabrication and construction?
  - How would you describe your role during fabrication and construction?
  - Did anyone have any previous experience with modular?
  - What were your goals with regard to Sustainability?
  - What issues did the team seem most concerned about?
    (Team = Architect, Engineers, Builder, Owner, etc.)
  - Were there any major conflicts or critical successes with the team?
  - What decisions were not made in your best interests?
  - What decisions were you most pleased with any why?

Project questions
- How long was the design time?
- How long was fabrication time?

Location
- Were there any problems or benefits with team member physical locations?
- Where the site was?
- Where materials came from?
- Were there any codes that presented any problems?
- Were there any codes that helped in any way?
Organizational Factors
Contract Factors:
- How were legal/contractual obligations organized?
- Who was responsible to whom (financially/contractually)?
- Were there any problems or "kinks" in this structure?

Financing Factors:
- How were finances organized?
  (Permanent loan, alternative financing option)
  Were there any problems or successes in financing?
  Was the project profitable for you?
  Did it meet your economic needs?

Integration Factors:
- With whom did you primarily coordinate?
- Were there any problems?
- Do you consider the workflow to have been successful and sustainable?

Technological Factors
- How did you communicate with the team?
  Traditional drawings or did you coordinate with BIM? Which platform?
- What kind of prefab technology was used?
  Who designed it?
- How were modular components assembled to each other on site?
  Who designed it?
- How were modular components assembled to the site built work?
  Who designed it?
Appendix 2: Process of Coding

1. Questions to ask
   a. Charmaz
      i. What is going on?
      ii. What is the person saying?
      iii. What do these actions and statements take for granted?
      iv. How do structure and context serve to support, maintain, impede or change these actions and statements

2. What Codes Can Be About
   a. Lofland and Lofland
      i. Acts – Usually Brief events
      ii. Activities – of longer duration in a setting, people involved
      iii. Meanings – What directs participants’ actions?
      iv. Participation – Peoples involvement or adaptation to a setting
      v. Settings - The entire contexts of the events under study
   b. Strauss
      i. Conditions
      ii. Interactions
      iii. Strategies and tactics
      iv. Consequences
   c. Sabatier


Gibbs, *Analysing Qualitative Data*.


Strauss, *Qualitative Analysis for Social Scientists*.

i. Causal adequacy
ii. Financial resources
iii. Legal / Bureaucratic constraints
iv. Political / Interest group support
v. Official / Bureaucratic commitment
vi. Social/Economic Environment

d. Mason
   i. Literal – Words dialogue used, actions, settings, systems, etc.
   ii. Interpretation – Implicit norms, Values, rules, morals, how people make sense of phenomena
   iii. 3. Reflexive – researcher’s role in the process – how intervention generated the data

3. Ways to identify themes for thematic coding:
   e. A. Ryan and Bernard
      i. Repetitions
      ii. Indigenous typologies
      iii. Metaphors and analogies
      iv. Transitions
      v. Similarities and Differences
      vi. Constant Comparison
      vii. Linguistic connectors
      viii. Because, before, after, next, closeness, examples
      ix. Missing data (what is omitted)

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80 Mason, *Qualitative Researching.*
81 Ryan and Bernard, “Techniques to Identify Themes.”
### Appendix 3: Major Themes Identified From Qualitative Interviews

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