2018-06-01

A Systematic Process for Implementing Mass Customization in Residential Preconstruction

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

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According to production process theory, customization is directly related to cost and inversely related to volume, efficiency, and productivity. However, customers generally desire products that are individually tailored to their wants and needs. For this reason, as residential contractors grow, they struggle to meet customers' demands for flexibility. This struggle to increase customization is not unique to the construction industry and many other industries have studied this problem in depth. While the inverse relationship between customization and cost is generally true, mass customization can enable increased customization with limited or no increased cost. The residential construction process employs many mass customization enabling principles, including modularity and product family design. However, the preconstruction process fails to employ these same principles. The purpose of this study was to explore how mass customization principles can simplify customization in the residential preconstruction process. Two rounds of interviews were conducted with residential construction industry preconstruction experts. Using their input, a process for implementing mass customization was developed. The results demonstrate that implementing mass customization principles can greatly simplify the purchasing, estimating, and option pricing processes for residential contractors. However, mass customization also significantly affects company structure, cost control strategies, trade relationships, and leanness. This research is enlightening to residential contractors struggling to manage customization. It also provides direction for software developers targeting the residential construction processes.

Keywords: residential construction, residential preconstruction, mass customization, modularization, product family architecture, estimating, purchasing, standardization, option pricing, product process matrix

ACKNOWLEDGEMENTS

As always, there are too many people to thank, and this page seems short. If I miss someone, I apologize.

First, I would like to thank my Heavenly Father for insight and experience which made this research better than I could imagine, and guidance on how to finish it. Without His help, I never would have finished. His house greatly calmed my troubled mind on many occasions.

The faculty at BYU for their enduring support. Specifically, Brother Farnsworth for listening and giving me a voice. He spent many hours trying to understand obscure connections I had made. He was always the first to understand these connections and molded them into logical arguments. Brother Miller for encouraging me and providing the opportunity to obtain my master’s degree. Brother Christofferson for pushing me towards excellence. Brother Smith for being the pinch hitter. And Sister Lowe for her help editing.

The many industry professionals who dedicated significant time teaching and hypothesizing about the industry. Hopefully, this research will pay back your time with interest.

My father, for always being excited about the same nerdy topics. No one else I know spends Christmas break in intellectual discussions about BIM, estimating, and technical writing. Also, for his consistent dedicated work. I learned more about a father’s love from this paper than any other experience. My mom for never letting me fail. I could never bear the disappointment of being any less than you see me. My 7-month-old daughter Renee, for being patient. Much of this research was written while she was in my arms or sitting next to me. She found the keyboard more than once, so any typos can be blamed on her.

Last, my wife Noelle, for talking with me. Everything is better when we are talking.

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1 INTRODUCTION

Flexibility and customizability can be important sources of volume, revenue, and profitability for home builders (Pine, Peppers, and Rogers, 2010). High levels of customization are commonly cited in sales literature as an important method to increase traffic and sell more homes (Bady, 2018), and few builders can survive without allowing some level of customization (Broad, 2013).

The need for customization is also driven by the construction process. Because shipping completed homes is typically unfeasible, contractors have a much smaller market of customers to draw from. Without some level of customization, subdivisions would quickly become saturated with identical homes. This contrasts the typical manufacturing process, where volume is maintained while avoiding product saturation, because customers are spread over a large geographic area. The construction process's push for customization is true even for national, or regional builders, because the construction process is still localized.

Despite the sales/marketing need for customization, highly efficient processes have traditionally required a high degree of standardization. (Deming, 1986; Sedam, 2011f). Customization adds complexity, making process efficiencies harder to achieve. The relationship between process efficiency and standardization is very strong. In fact, production strategy typically views flexibility and customization as directly related to cost and inversely related to productivity (Clark, 2012; Hayes and Wheelwright, 1979b). The same is true for residential contractors. Many who allowed significant amounts of customization have found it becomes unmanageable, and seek to simplify by removing options and significantly decreasing offered floor plans (Bousquin, 2015b; Kerwin, 2005).

Due to the difficulty with customization, many successful production homebuilders have identified niche groups of customers, and targeted them with a limited array of options (Bousquin, 2015b; Kerwin, 2005). This strategy helps maintain an efficient production process. However, contractors can also miss essential customer preferences. As Bousquin (2015b) states, "[with builders] you see the mistake again and again where you have a successful series in one location, so you try to put it somewhere else. The truth is, every street corner is different."

Another difficulty with niche markets is customers don't fit into such nice neat groups. This becomes a problem as competitors, seeking to target overlapping niches, begin bombarding customers with a confusing array of choices that identify with different customer preferences (Pine, Peppers, and Rogers, 2010). Ironically, research has shown that as customers wade through these choices seeking the best option, the vast array of slightly incorrect options can "debilitate" customers' ability to make choices (Schwartz and Kliban, 2004). As another author puts it, "customers…do not want more choices. They want exactly what they want—when, where, and how they want it" (Pine, Peppers, and Rogers, 2010).

Researchers of marketing strategy have noticed the negative effects caused by bombarding customers with too many choices. However, a complete lack of choice is also not the answer. Schwartz and Kliban (2004) state, "when people have no choice, life is almost unbearable." Instead of trying to walk the delicate balance between too little and too much choice, some studies have advocated a complete change in marketing strategy. Rather than identifying the needs of groups of people and seeking to target these groups, these researchers advocate a customer centric design and production process where the product is designed to each individual's needs (Duray and Milligan, 1999; Dedrick and Kraemer, 2007; Pine, 1999). When properly executed, such a system can insulate a customer from choices they find irrelevant, while also meeting the customers' individual demands (Zipkin, 1997). The challenge is designing such a system to allow the efficiency and cost of mass production, while offering such a broad array of flexibility.

Since the 2008 recession, the debate over how to customize efficiently has become especially relevant. As the market has tightened, home buyers have become more selective in their purchases, forcing builders "to be as nimble as a Romanian gymnast in adapting—at all stages of design and construction—to the whims and wishes of buyers and their moving target floor plans" (McManus, 2015a). A recent study showed that 71% of Millennials want the ability to customize their home, with 22% being the average amount budgeted for these customizations (McManus, 2015b). Research on customization management strategies have focused on defining a core niche of customers and designing floor plans and options to meet their needs (Bousquin, 2015a; Kerwin, 2005; Rashkin, 2015). However, niche option strategies can result in thousands of options, as finish options exponentially compound with each added structural option. Many who have tried customizing large volumes of homes have found that it resulted in an unfeasible preconstruction process resulting in "option overload" (Bousquin, 2015a). In addition, option heavy contractors struggle to clearly define which customization requests they can or will entertain—wasting valuable time trying to price options that they are ill equipped to offer.

In manufacturing, there has been some success developing processes which allow a high degree of efficiency, and a high degree of flexibility. In the literature, these strategies are typically termed mass customization (Pine, 1999). Within mass customization literature, there are two broad strategies to increase flexibility. First, Roach, Cox, and Sorensen (2005) advocate developing product families with standardized components and production processes. These families can then be stretched and scaled to meet customers' demands. Second, Duray, Ward, Milligan (2000) isolates subassemblies, or elements of a completed product, and standardizes their size and connection requirements. These subassemblies can be substituted to achieve different looks and functionality.

There is little literature explaining how to apply mass customization principles to residential construction. However, it appears that market forces have caused construction practices to adapt mass customization principles. Most building assemblies have developed into generally applicable and stretchable assemblies advocated by Roach, Cox, and Sorensen (2005); finishes are commonly componentized with standardized connections (Duray, 2002). This has provided the construction process with flexibility, especially among smaller builders.

As residential contractors grow in volume, current preconstruction processes create significant customization limits. As departments specialize, it becomes increasingly difficult to accurately communicate customer's desires, implement purchasing negotiation techniques (Sedam, 2011a), and maintain finish option pricing on semi-custom products (Bousquin, 2015b). Additionally removing the waste inherent in generic assemblies is important for profitability (Sedam, 2017); Residential contractors appear to standardize to simplify the preconstruction process, not because the construction process demands it.

Given the market's demand for customization, residential contractors need additional insight on customizing effectively, especially regarding the preconstruction process. The principles found within mass customization are a promising avenue of research. These principles include modularization—to prevent changes cascading into other processes—and integrating parametric design into existing business practices. This research attempts to identify how these principles can be applied effectively to the residential preconstruction process.

1.1 Problem Statement

The current preconstruction processes used by residential contractors make it difficult to meet the customer's demand for customizability.

1.2 Objective of Study

The purpose of this study is to develop a preconstruction process which allows residential contractors to mass customize. This process would include the following points:

- Applying the mass customization principle of modularity to the preconstruction process
- Demonstrate how to price structural and finish options independently
- Identifying how customization affects sourcing strategies so informed decisions can be made on the level of customization offered
- Demonstrate how to clearly define and articulate the limits of customization

1.3 Mass Customization

Typical production process literature indicated an inverse relationship existing between the level of standardization/customization, and productivity/cost (Clark, 2012; Deming, 1986; Hayes and Wheelwright, 1979b). While the relationship was well established generally, researchers identified ways to break the relationship in limited circumstances. These efforts to improve both flexibility and efficiency were collectively termed mass customization.

Mass customization broadly fell into two categories. One defined the elements and processes by which a product was produced without defining its size (Roach, Cox, and Sorensen, 2005). This allowed similar products to be produced in a variety of sizes. Others standardized how subcomponents (parts of a completed product) attached to the main component. This allowed modularization, or elements of a completed product to be replaced without redesigning the entire product (Duray, 2002; Pine, 1999).

The research on mass customization was sparse. However, it appeared market forces had driven construction processes to adapt mass customization practices. Due to this relationship, understanding these processes and how they relate to design and preconstruction is an important element of customizing effectively.

1.4 Parametric Design and Building Information Modeling (BIM)

Parametric modeling systems are a foundational element of one form of mass customization (Roach, Cox, and Sorensen, 2005). These modeling systems (termed Building Information Modeling or BIM in the construction industry) define graphical entities through parameters or characteristics of its physical counterpart. For example, a door would be defined by its width and height; the width and height of its stiles, rails, panels; location of the knob, deadbolt, hinges; etc. This contrasts with direct modeling, or coordinate modeling, where entities are stored as numerous x, y, and z coordinates with no relation to what they are, or how they behave in the physical world (Autodesk, 2007).

The parameters of a parametric model allow increased efficiency of the design process, and integration with, and automation of some back office tasks (Roach, Cox, and Sorensen, 2005; Nassar, 2012; Nellis, 2012; Sedam, 2011c). In a mass custom environment this automation is essential to maintaining efficiency and profitability, correctly ordering materials, paying suppliers, and communicating changes.

The relationship between parametric modeling and mass customization make BIM modeling a promising avenue for increased flexibility in residential preconstruction. However, BIM models are difficult and time-consuming to set up (Sedam, 2011c; Sedam, 2011d; Sedam, 2011e). Simply drafting a house in BIM software system does not ensure that the data produced meets the needs of the preconstruction process. Additional research is needed on integrating these models into the preconstruction process.

1.5 Definitions

The following terms are defined here to provide context for how they are used throughout this thesis:

Building Information Modeling (BIM) – A parametric modeling tool used within the construction industry.

Bid Payment Structure – A formal bidding process, where a lump sum payment is negotiated for every specific plan and option available.

Componentization – Standardizing elements of a building so they can be produced more efficiently, offsite, in a controlled environment.

Custom Home - Designing and constructing a new house without relying on a contractor's master house plans.

Mass Customization – A group of methods used to increase productivity and reduce cost in a highly custom environment. These processes fall into two generic categories: modularization (i.e. customizing by replacing elements of a product) or product family architecture (i.e. methods to produce standard products in a variety of sizes).

Modularization – A form of componentization used in mass customization. In modularization, similar products are produced with standard connection requirements. Customization is achieved by swapping components to achieve a different look or function.

Parametric Design – A design process that contains "intelligent" objects that are linked together and update together. The process can also calculate the object's parameters (e.g. height, depth, area, count, etc.).

Product Family Architecture – A form of mass customization in which a process is developed to produce similar products in a variety of sizes. Because important elements of the product are standardized, the process can achieve a high degree of efficiency.

Product Process Matrix – A matrix used in the manufacturing industry to link manufacturing and marketing strategies.

Semi-Custom Home – Altering a contractor's master house plans outside of any standard options list.

Unit Price Payment Structure – Payments are negotiated based on specific key measures and materials. This structure is ambivalent to plans and options. (e.g. paying roofers per sq. of shingles installed). The structure can be highly detailed (e.g. tracking drip edge, gutter flashing, and nails), or simply detailed (e.g. paying roofers a turnkey price based on sq. of shingles installed).

2 LITERATURE REVIEW

This chapter addresses the challenges contractors face when customizing large volumes of homes. In construction literature, it was unknown why home builders lost the ability to customize as they grew. Intuition would argue that constructing a production home is more efficient than constructing a custom home. However, there was little written on where efficiency was gained, how to quantify those efficiencies, or even if efficiencies really were gained by production home building. A review of literature from other industries implies that the majority of efficiency gains through standardization came from reduced managerial burden and not process efficiencies, and by developing adaptive managerial processes (e.g. automating home estimates), homes could be customized more economically on a large scale.

Sections 2.1 and 2.2 explore specific processes that have successfully made the manufacturing industry more efficient. Studies in manufacturing have analyzed the effects and efficiencies of product standardization in great depth. The literature shows that standardization greatly increased production efficiency by enabling the use of custom equipment and machinery (capital equipment). This was pertinent to construction, because production home builders do not typically employ capital equipment and have therefore not seen the subsequent transformative efficiency gains seen in manufacturing. Over the past 100 years, there have been multiple attempts to mimic manufacturing's efficiencies by employing custom capital equipment. However, they have largely failed to achieve widespread use and highlight the unique challenges of using standardization in construction to increase efficiency. Understanding the advantages and disadvantages of standardization in the manufacturing industry provide an important context for studying standardization within the construction industry. Sections 2.3 and 2.4 explore standardization within the construction industry in greater depth, specifically looking at how the construction industry has used capital equipment, if it has resulted in productivity increases, and if the industry has standardized for the same reasons.

While standardization generally required specialized capital equipment to achieve mass production, there has been some research on developing production processes that are both flexible and efficient. Section 2.5 outlines the methods that were used to increase process flexibility. These methods were significant because the residential construction process employs many of these methods (e.g. modularization, interchangeable components, and assembly building methods). Due to these methods, the residential construction process should have had the ability to customize on a broad scale.

In contrast to the construction process, the residential preconstruction process appeared to limit customization. Section 2.5.2 and 2.5.3 outlines ways in which preconstruction did not employ the same methods necessary to achieve mass customization. It also highlights how mass customization methods conflicted with established business practices. In addition, this section identifies the strategic decisions that were necessary to implement a parametric modeling process (e.g. Building Information Modeling or BIM process) seen in many mass customization environments. The literature on how to overcome these conflicts and increase the flexibility of the preconstruction process was limited and is therefore the basis for this research.

2.1 The Industrial Revolution and the Effect on Home Construction

Meeting the demands of a customer is the heart of success for a business. However, customers are fickle and meeting such demands can be difficult. As Pine, Peppers, and Rogers (2010) stated, “customers whether consumers or businesses, do not want more choices. They want exactly what they want—when, where, and how they want it.” In the days before the industrial revolution, manufacturers (e.g. blacksmiths and carpenters) met the demands of customers by hand crafting unique items that exactly met a customer’s needs. While such products met a customer’s demands, the process of producing a single unique item was inefficient and expensive.

This section shows that during the industrial revolution, manufacturers realized that they could produce products much more inexpensively by employing specialized capital equipment. One requirement of using such equipment is the standardization of products. However, simply standardizing products does not change the customer’s unique demands. To combat varying preferences, manufacturers transitioned from meeting the demands of all customers in a small geographic area to targeting small groups of like-minded customers in many different geographic areas. The benefits of this specialization are still being felt today with manufacturers having increased productivity almost every year since 1954, resulting in more than a 200% increase in productivity (Kennedy, Daneshgari, Galloway, 2009).

2.1.1 Manufacturing Increases Productivity Through Standardization

One of the most significant and important advances of the industrial revolution came during the early 1800’s. At this time Britain was at war with France, and the British navy was under immense pressure to increase the production of ships. One particularly time-consuming aspect of the ship construction was creating hundreds of wooden pulley blocks to help raise and lower sails. The wartime demands exceeded 100,000 pulley blocks/year. During this period, Marc Brunel and

Henry Maudslay invented some 45 specialized machines to produce the blocks much more efficiently.

The manufacturing of wooden pulley blocks may be considered insignificant by today's standards. However, this represents the birth of the modern manufacturing era and highlights several significant advances that occurred. Most notably, the blocks were produced almost entirely on specialized equipment to very high tolerances. The machines dramatically decreased the time necessary to produce each block, and they were able to achieve a steady flow of production by using additional machines on time-consuming processes. As Beamish (1862) notes, the machines made it possible that "ten men, by the aid of this machinery, [could] accomplish with uniformity, celerity and ease, what formerly required the uncertain labour *[sic]* of one hundred and ten." (Coad, 2005).

Due to the limitations of the specialized equipment, the pulley blocks were standardized to three separate sizes. Three different sets of machines were then made which could produce blocks in one of the three sizes. Prior to the invention, the blocks were handmade, and could vary in size to meet the block's specific need (Coad, 2005). The blocks were also the source of political upheaval and contention from skilled laborers whose jobs were lost to industrialization. For this reason, the significance of the pulley block machinery was not realized for many years. Eventually the idea spread to America where standardization and mechanization were used successfully to increase the productivity of rifle production by 550% (Woodbury, 1960).

Another significant advance in manufacturing processes came from the mass production of cars. In the early twentieth century, automobiles were "made to order by craftsman, fitting parts together for a particular vehicle" (Crowley, 1998). In addition, the chassis was typically made separate from the interior and body, these being produced by the same companies that manufactured horse drawn coaches. The lack of specialized manufacturing equipment allowed each individual car body to be a unique custom design, which was common during the era (Georgano, 1990; Georgano, 1973). While this manufacturing method allowed a great deal of flexibility in car design, it was also expensive and thus made cars a luxury item affordable only by a select few.

Shortly after the introduction of the automobile Henry Ford realized that modern manufacturing techniques could allow cars to be produced much more efficiently and inexpensively. As stated in his autobiography, they initially sold 3 models – the R, S, and T (Ford, 2007). While these three models were successful and inexpensive—the model T had already sold more vehicles than any other manufacturer—he later realized that there were advantages a "single model would bring about in production" (Ford, 2007). Additionally, through standardization he could increase the productivity of his workers by using specialized capital equipment.

Henry Ford was relentless in his desire for a uniform standardized product (hereafter known as the Uniform One Model Policy). He even standardized the paint color famously stating, "any customer can have a car painted any colour *[sic]* that he wants so long as it is black" (Ford, 2007). While this decision may seem arbitrary, it had great significance in his production. Black paint simply dried faster than other colors, which was necessary to accommodate the assembly line. The Uniform One Model Policy was very successful. Between 1910 and 1925, Ford was able to reduce the sales price of the Model T by 70%, by greatly increasing his worker's productivity. He stated that in 1908 his workers produced on average 3.14 cars/year/worker, but that by 1911 his workers were producing 8.52 cars/year/worker. In his own words he credited this productivity increase to, "the application of intelligently directed power and machinery" (Ford, 2007). He eventually sold over 16 million Model T's, making Ford Motor Company the largest car manufacturer for over two decades (Collins, 2007).

To summarize, there are several important lessons to be learned from the advancement of manufacturing processes. One of the greatest advances of the modern age came from using specialized capital equipment to greatly increase a worker's productivity. Because specialized equipment generally had inflexible processes, this equipment requires the standardization of products. It was shown in both examples (pulley block and car manufacturing) that manufacturers had greatly increased productivity by using specialized capital equipment, allowing manufacturers to produce more products using less labor, less skilled labor, and at a lower price. In this environment, standardization was necessary due to the limitations and constraints of the capital equipment imposed on the product. The idea of standardization within the construction industry is further explored in sections 2.3 and 2.4, examining how these same principles apply.

2.1.2 Manufacturing Adapts Process to Meet Customer's Demands

While the previous section explored the benefits of standardization, this section shows that standardization did not change customer's demands for individualized products. Further, while price is a very important factor in the buying decision, it is not the only factor. This section also demonstrates that all else being equal, customers choose unique products that better suit their needs over a standardized product.

As successful as Henry Ford was at increasing productivity and lowering price through standardization, his ideas were not without opposition. As he stated, "I cannot say that anyone agreed with me [regarding the Uniform One Model Policy]. The selling people could not of course see the advantages that a single model would bring about in production" (Ford, 2007). A conversation between Henry Ford and his salesmen highlights some of these concerns.

> The salesmen…were spurred by the great sales to think that even greater sales might be had if only we had more models. It is strange how, just as soon as an article becomes successful, somebody starts to think that it would be more successful if only it were different. There is a tendency to keep monkeying with styles and to spoil a good thing by changing it. The salesmen were insistent on increasing the line. They listened to the 5%, the special customers who could say what they wanted, and forgot about the 95% who just bought without making any fuss…When [a complaint or suggestion] is only as to style, one has to make sure whether it is not merely a personal whim that is being voiced. (Ford, 2007)

While Henry Ford refused to listen to the 5% and provide unique styles, features, and colors to the Model T, another company did listen. In 1914 Chevrolet introduced a car with the intent of competing with the model T on price and volume. However, they quickly realized that it was impossible to "match the scale and profits of Ford" (Phillips, 2011) and decided "to change the game itself…[by] creating a car for every purse and purpose" (Friedman, 2014). This strategy of targeting a variety of customers with a variety of models and options led Chevrolet to become the second largest car manufacturer by 1919 (Phillips, 2011). Shortly after the Model T was discontinued, GM (the parent company of Chevrolet) became the world leader in car sales, simply by targeting a customer's desire for options (Sloan, 1964). This strategy was successful because it allowed GM to identify simple changes with large value to some customers (electric lights, starters, and increased horsepower). While these customers couldn't afford a truly custom car, they were able and willing to pay more for a car with these conveniences.

Toyota further refined this strategy. Due to import and export restrictions following World War II, the Japanese car market was too small to successfully implement the mass production strategies used by American car manufacturers. Due to these restrictions, Toyota was forced to assemble different car models on the same production line. The Toyota production system allowed increased customizability (through multiple models) while maintaining or increasing the efficiencies of American car manufacturers (Cuperus, 2003; Crowley, 1998). The success of these companies showed that an increased level of customization and options could be very desirable to a customer and could lead to a business's success if the production was handled efficiently.

As car manufacturers have shown, efficiency and providing a large variety of products for customers to choose from are both essential. The business strategy of using customization and options to attract customers has also been used successfully by many companies including Dell (Dedrick and Kraemer, 2007; Duray and Milligan, 1999), Burger King (Surprenant and Solomon, 1987), McDonalds (Clark, 2012), Google, and others. The success of this strategy shows that while customers generally desire low cost items, they also trend towards items tailored towards their individual needs (Goldsmith and Freiden, 2004). Can this be used successfully in the construction industry? Traditionally residential construction has allowed a great deal of freedom and flexibility in the home design. However, with the advent of production home builders, most residential contractors have moved away from custom designs towards a more uniform and efficient design method. This trend has limited the amount of flexibility that customers had traditionally enjoyed.

2.2 Residential Construction and the Product Process Matrix

In the previous section it is shown that manufacturers have standardized to allow the use of specialized capital equipment, and due to that equipment, they were able to greatly reduce cost. It is also shown that simply standardizing does not remove the desire of the customers for individually tailored items. This section introduces the product process matrix. Once a manufacturer has identified a marketing strategy—such as cost leadership, responsiveness, or differentiation—the product process matrix shows the correct type of equipment to employ and the corresponding most efficient production method (Clark, 2012). The next section will demonstrate how this matrix can be applied to the construction industry.

2.2.1 Overview

The product process matrix (shown in Figure 2.1) was originally developed by Hayes and Wheelwright (1979b) to identify the optimal method to produce a product. It is a strategic tool that helps managers "choose among various manufacturing and marketing options" (Hayes and Wheelwright, 1979b; Clark, 2012). Businesses could "secure a competitive advantage by putting its primary focus into one of three areas: (1) differentiation, (2) cost leadership, or (3) responsiveness" (Clark, 2012). The product process matrix adapts the manufacturing process to pursue these strategies with the least amount of waste, by linking a product's design with the number and skill of employees, types and purpose of production machinery and equipment, and the level of efficiency vs. the level of customer responsiveness (Clark, 2012). Products produced along the diagonal axis in the matrix maximize production efficiency for a set level of production flexibility, while products not on the axis result in either wasted products (bottom left of matrix) or are unnecessarily expensive and/or inflexible (top right of matrix). In residential construction, contractors have been unable to reach the highly efficient processes in the bottom right corner of the matrix (Hayes and Wheelwright, 1979a).

In the product process matrix, highly flexible processes (in the top left of the chart) use generalized equipment and highly skilled labor to create "custom products." Machine shops, tool manufacturers, and die manufacturers have been identified as excellent examples of this manufacturing process (Inman, 2014). The equipment tends to be general purpose because each job is unique, arrives in different forms, and requires different tasks (Hayes and Wheelwright, 1979b). Also, the equipment is seldom used at 100% capacity and the workers typically have a wide range of production skills. Because each job is unique, automating tasks with equipment is difficult, which limits the efficiency of the production process. However, the production process is also very flexible, in that it allows manufacturers to make a great variety of products.

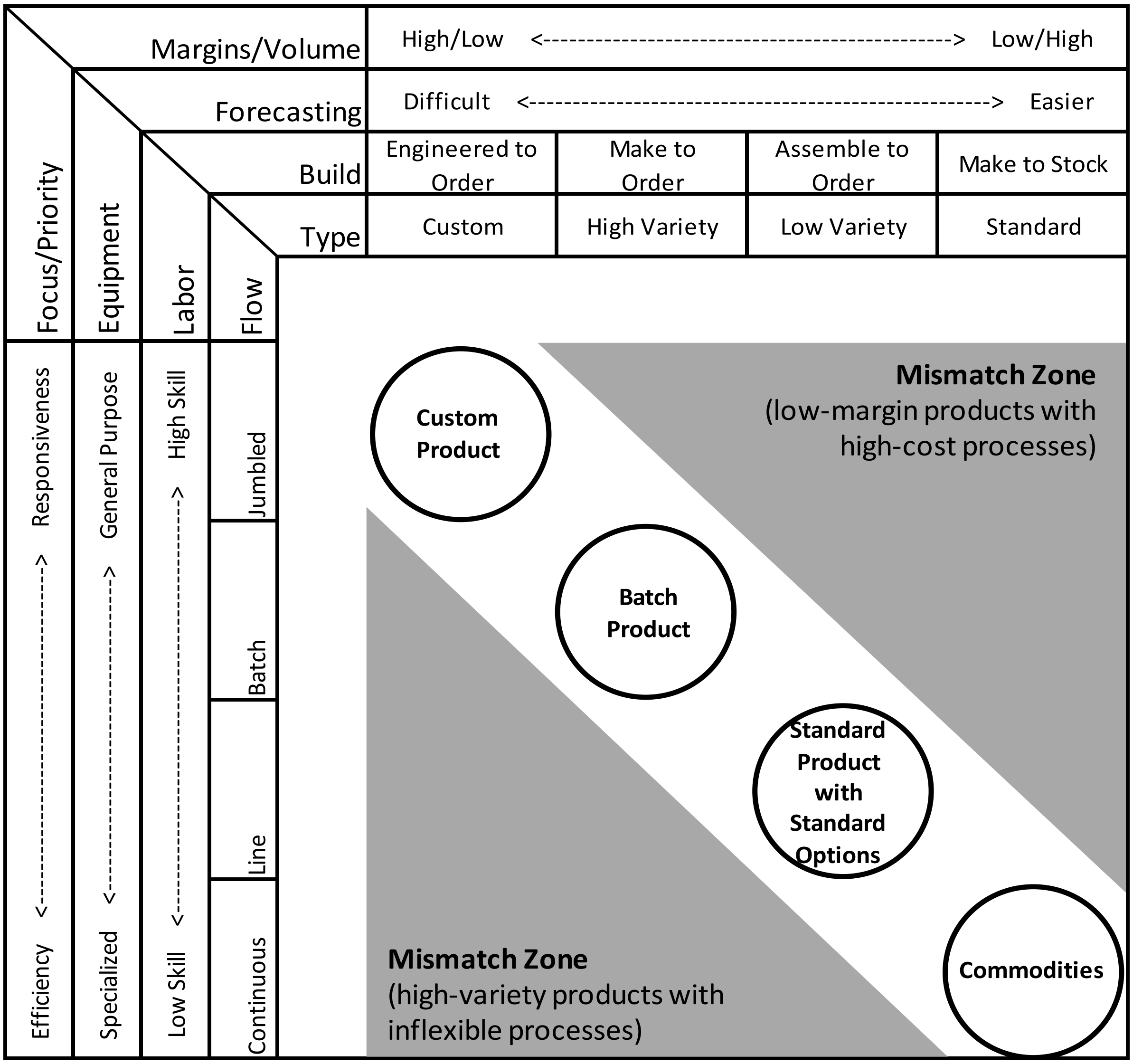

Figure 2.1: Product Process Matrix

Increasing efficiency requires producing larger numbers of increasingly similar products. This is shown in the product process matrix by shifting downward along the diagonal. The next stage following custom products are "batch products," where products are highly customizable, but have similar features. This production process still uses very general-purpose equipment to maintain production flexibility. However, the equipment is arranged according to the production processes rather than the type of equipment. This allows for a much smoother production process (Inman, 2014). Additionally, a low volume assembly line, or simple jigs could also be used to increase productivity. An excellent example of the batch production process could be found in a custom cabinet shop. Cabinets have many customizable features (e.g. type of wood, door profiles, hardware, pullout trays and racks, finishes, etc.). However, many of these features would be identical in a set of cabinets (e.g. identical profiles and finishes on cabinet doors), which allows the machines to be arranged by process and set up only once per batch. This in turn reduces travel and set up time and would therefore increase productivity. Employees could also gain a degree of specialization, learning only a portion of the processes, as opposed to the entire process.

Line or continuous production processes (bottom right of matrix) are used to mass produce products. These processes required large volumes and a high degree of standardization (Inman, 2014). The volume of product allows employees to specialize in one or two processes, which further allows the company to hire lower skilled employees. In addition, the standardization allows the development of specialized equipment to increase the process efficiency (Clark, 2012; Ford, 2007). The process Henry Ford developed to manufacture automobiles (outlined in section 2.1.1) was an excellent example of the advantages and disadvantages of this production method, dramatically decreasing cost, but also decreasing the options a customer could select from. In the extreme bottom right of the matrix ("commodities"), customers are left without any options (Inman, 2014).

There has been some debate as to where construction processes should fit within the product process matrix. Inman (2014) added a fifth "project" stage in the upper right corner of the matrix, and defined these products as “large scale, one-time, unique products… [that were] customer specific and often too large to be moved.” However, Hayes and Wheelwright (1979a) recognized that with increased volumes, construction products could also move down the diagonal of the matrix. Section 2.4 shows that the construction industry had attempted to move diagonally down the matrix, but difficulty in shipping the product from the capital equipment to the site or shipping the capital equipment to be utilized at the site limited success.

2.2.2 Strategically Using the Product Process Matrix

The product process matrix has great strategic importance to a business. The matrix helps develop a unique production strategy to complement a niche identified in the market. By identifying competitors’ strategies and where they sat on the matrix, underserved customers can be identified and targeted with a complementary production strategy (Hayes and Wheelwright, 1979a). This section provides a case study using the product process matrix adapted to the early automobile industry (See Figure 2.2). A case study for the residential construction industry will be further developed in Section 2.3.

The history of automobile manufacturing (outlined in section 2.1) provided an excellent example of how the product process matrix can be utilized. Automobiles were originally manufactured as unique custom products (upper left of matrix). To complement this strategy, car manufacturers designed and manufactured unique car bodies for individual customers (Georgano, 1990; Georgano, 1973). Henry Ford recognized that the responsiveness strategy of these manufacturers priced a significant number of customers out of the market. Henry Ford also recognized that a cost leadership strategy (bottom right of matrix) could be very successful and adopted this strategy for Ford Motor Company. To complement this cost leadership strategy he standardized the Model T, and developed the specialized equipment that would allow him to increase productivity and decrease cost (Hayes and Wheelwright, 1979a; Ford, 2007).

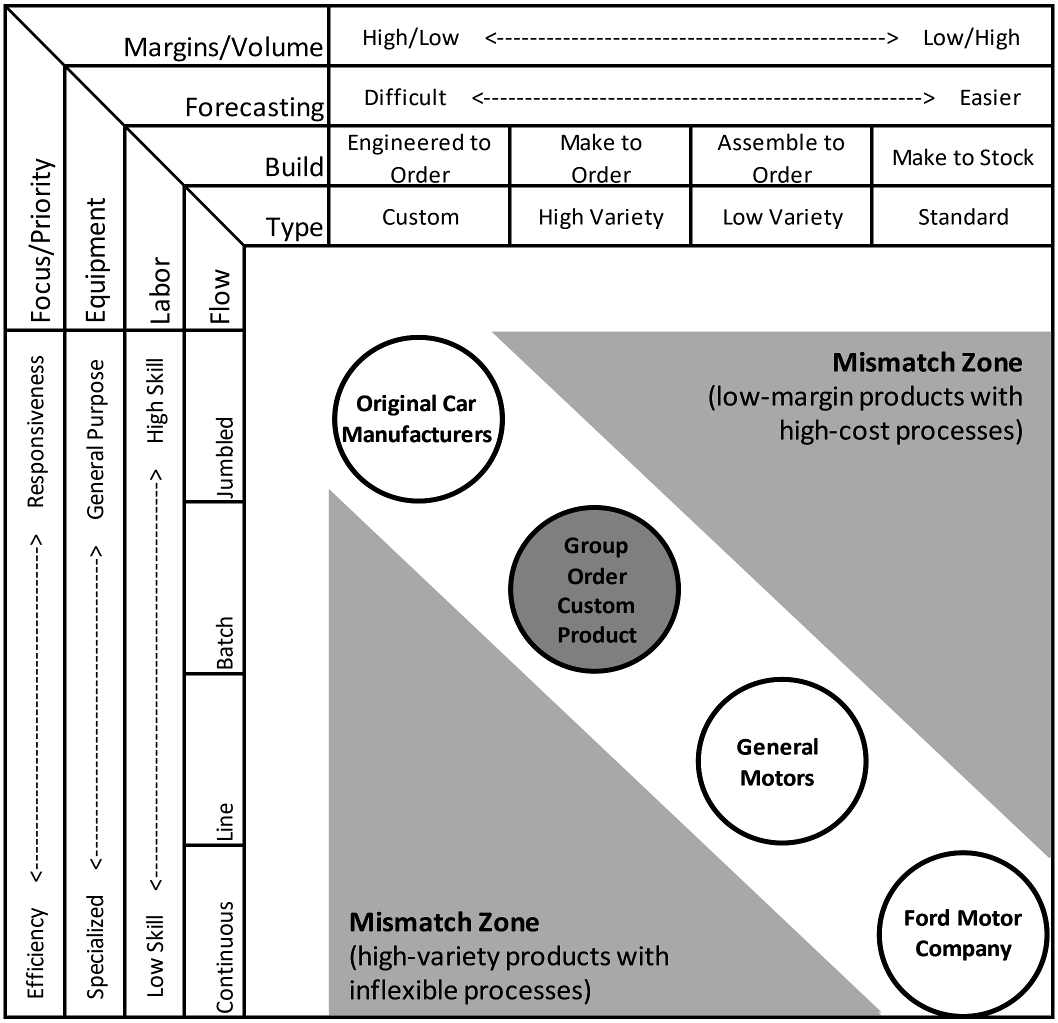

Figure 2.2: Product Process Matrix for Early Automobiles

Henry Ford's cost leadership strategy was initially successful. However, General Motors recognized this strategy standardized the product more than the customer desired. By shifting diagonally upwards one level on the matrix, they were able to differentiate their product allowing them to target several different customer groups. This strategy was a great success. They used many of the specialized pieces of equipment developed by Ford, but also allowed the customers an increasing variety of options. While their cars were less efficiently produced and more expensive than Ford's, the flexibility they offered the customer was well received. This made them very successful (Hayes and Wheelwright, 1979a).

2.2.3 Mismatch in the Product Process Matrix

The product process matrix also identifies mismatches between product type and process type. While such mismatches can exist, they are dangerous because they result in waste and inefficiency (Clark, 2012). In this section, a production case study regarding McDonalds Corporation is presented, demonstrating the danger of a mismatch between product type and process type. By recognizing a mismatch between production and product type, companies within any industry could adapt to maximize efficiency, productivity, flexibility, and profitability by using the most efficient and flexible processes possible.

In the 1970's, McDonalds had a very simple menu consisting of six entrees (two hamburgers, two cheeseburgers, Big Mac, and fish fillet), fries, apple pie, and drinks. To complement this very standardized menu, their production process prized efficiency, and all their burgers were made prior to a customer's order. Due to their focus on efficiency, low cost, and their specialized made to order processes, Clark (2012) placed them near the bottom right of the product process matrix (See Figure 2.1).

As the competitive landscape changed, most significantly with Burger King's®, "have it your way" campaign, McDonalds responded with additional items to their menu. However, McDonalds maintained highly efficient inflexible production processes. Since they had difficulty forecasting the demand for every product type, they ended up discarding a large amount of product. Due to the change in marketing strategy, McDonalds had shifted themselves into the lower left mismatch zone (Clark, 2012). Eventually, this waste justified changing to a more flexible and less efficient production process: they developed a two-step process where hamburger patties were cooked prior to the customer's order and held in a special warming drawer. When the customer's order was placed, the burger was assembled to meet the customer's demands (Clark, 2012). Due to this change in production strategy, McDonalds then shifted upwards in the matrix to the standard product with standard options stage (Clark, 2012).

Mismatches between product and process type are dangerous because they have no value. When a business shifts into the bottom left of the matrix, businesses produce, and customers pay for products that will eventually be wasted due to forecasting errors. On the upper right of the matrix, businesses are producing a very standardized product, but lack the increased efficiency of mass production. This causes their sales price to be comparatively high, while they offer customers little or no unique features which would justify the increased price. In the next section, it is shown that the residential construction industry has been straying into a mismatch zone.

2.3 Applying the Product Process Matrix to Residential Construction

Section 2.2 shows how matching production and marketing strategy using the product process matrix (Figure 2.1) aids the development of a core competency. It is also shown that straying from the diagonal of the matrix is dangerous because it results in wasted products (bottom left of matrix), or products that are unnecessarily expensive and/or inflexible (top right of matrix). This section applies the matrix to the residential construction industry and shows the industry has strayed off the diagonal on the matrix, providing unique opportunities for construction companies within the industry.

There had been some debate how, or even if, the product process matrix could be applied to construction (See Figure 2.3). Some authors have felt the differences between the manufacturing and construction industries justified a new location for construction processes on the matrix. As previously mentioned, Inman (2014) included a fifth "project" stage in the upper left corner of the matrix (not shown). This view was prevalent due to the differences between construction and custom manufacturing. Custom manufacturing uses a jumbled flow production process. This process has several important elements (e.g. organizing tools according to type due to uncertainty in process flow, and training employees on many or all processes). The construction industry does not use jumbled flow processes. In construction, tools are brought to the project, process flow is organized during preconstruction, and employees have specialized training.

The researchers recognize that construction processes differed from manufacturing processes. However, guidance on increasing efficiency is an essential detail of the product process matrix. Relegating the construction process to a separate location on the matrix ignored the ability of the industry to improve productivity through the use of specialized capital equipment (Umberger, 2002). For this reason, construction was initially placed in the upper left corner of the matrix, while recognizing some construction processes that are farther down the matrix (i.e. mobile homes) (Hayes and Wheelwright, 1979a). While viewpoints differed on how to portray the industry, both recognized the difficulty the construction industry faced in achieving the more efficient batch, line, or continuous production processes further down the matrix. Figure 2.3 shows a version of the product process matrix adapted to the residential construction industry.

For many years, industry professionals have recognized the advantages of mass producing homes (bottom right on the matrix). Builders also have increasingly standardized floor plans in an attempt to increase productivity (Kerwin, 2005). However, the capital equipment that would allow such productivity increases has remained elusive due to unacceptable levels of standardization in a limited geographic area, shipping requirements, quality issues, and other factors (see section 2.4).

The product process matrix depicts this by showing the industry shifting into the upper right-hand mismatch zone (see Figure 2.3).

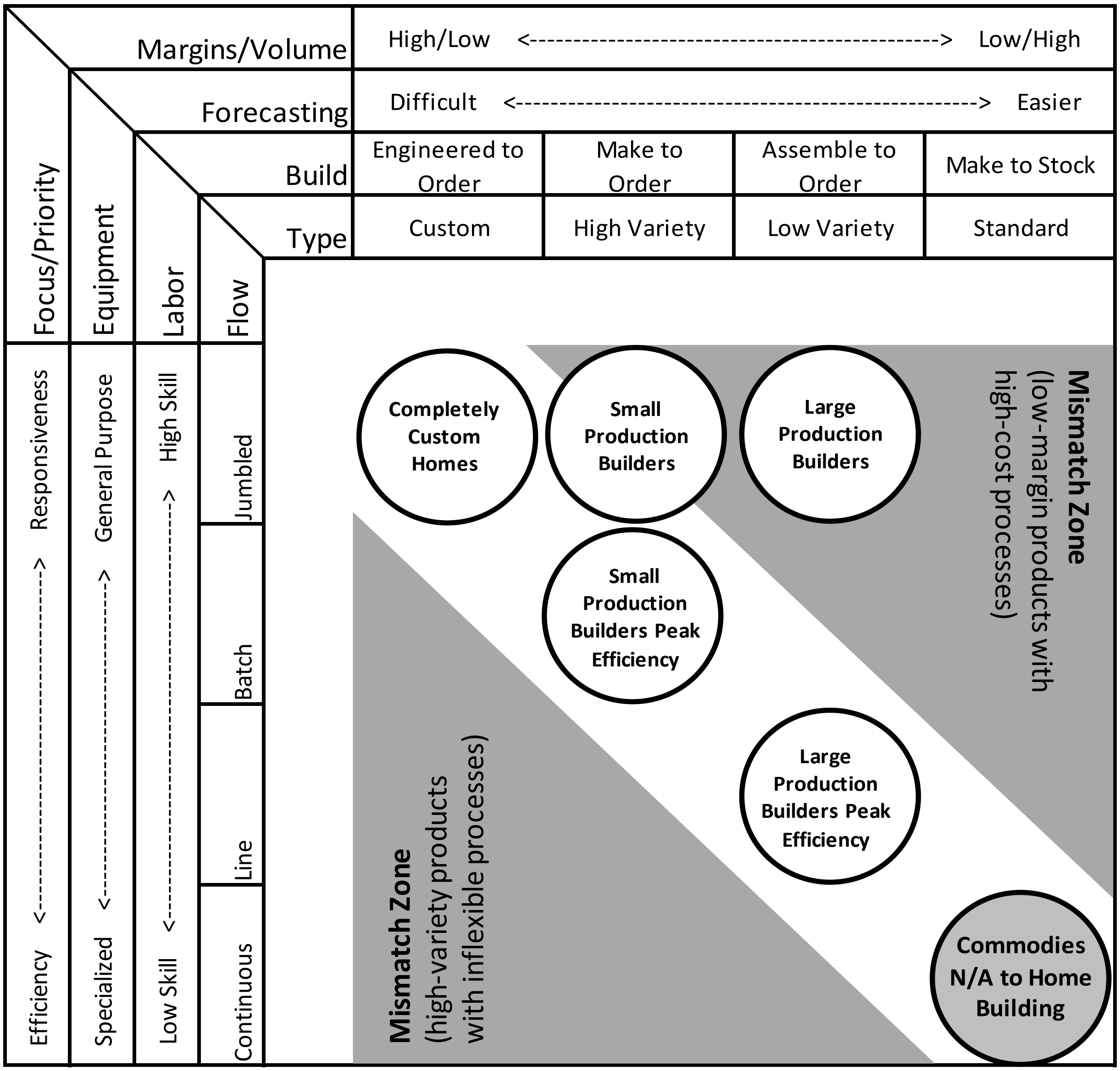

Figure 2.3: Product Process Matrix Adapted to Construction

Related fields in academic literature showed some debate whether this shift and its effects have been happening. As shown in Figure 2.4, the construction labor productivity index has remained stagnant for the past 30 years, while the manufacturing index has increased 100%. (Bureau of Labor Statistics, 2017). According to the product process matrix, the productivity gap may be the result of the manufacturing industry's continual investment in increasingly sophisticated capital equipment, while the construction industry has continued using highly skilled labor and general-purpose equipment. Others have simply argued that the gap is a result of errors in the BLS's methods of measurement and reporting (Kennedy, Daneshgari, Galloway, 2009; Allmon, Haas, Borcherding, 2000; Rojas and Aramvareekul, 2003). Unfortunately, the literature on this subject was inconclusive.

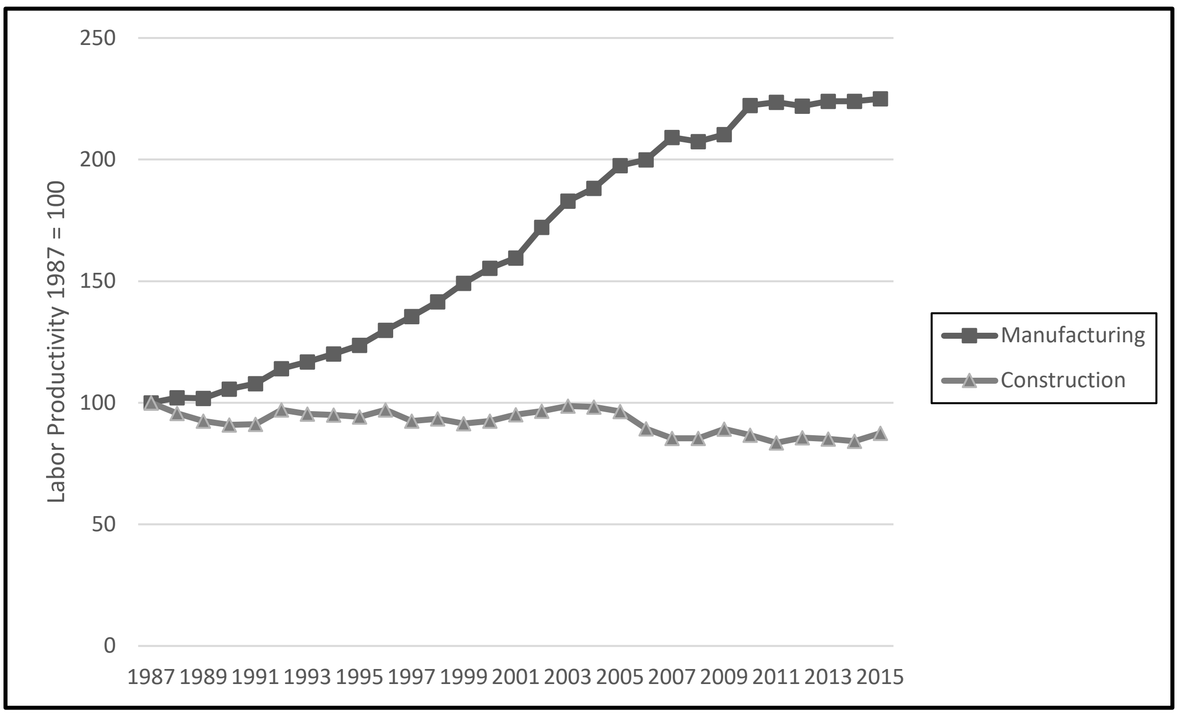

Figure 2.4: Construction and Manufacturing Labor Productivity Index

Edward Deming's research on Total Quality Management contained a similar line of reasoning to the product process matrix (Deming, 1986). According to the product process matrix, each type of process has inherent productivity limits, and achieving higher productivity can only result through a change in production process, such as through the introduction of capital equipment (Hayes and Wheelwright, 1979b). Similarly, Deming (1986) theorized that each process had a theoretical limit in how efficient/productive it can be, and that most processes were operating at or near that theoretical limit. He further hypothesized that without changing the production process in some manner, it is impossible to increase productivity. He did disagree that such a change must always come from the introduction of increasingly sophisticated capital equipment (as seen in the matrix). However, the argument of an inherent productivity ceiling that could only be breached through a change in process remained the same.

The current location of the home builders on the product process matrix is dangerous, because theoretically a company could offer greater flexibility to a customer with little increase in cost (See Figure 2.3). Most research has focused on shifting down on the matrix to decrease cost and increase productivity through mass production techniques. However, research in this area has run into a number of barriers, as explained in the next section (See Section 2.4). Another option is to shift left, and offer the customer greater flexibility and choice, as outlined in the McDonald's case study in section 2.2.3 or in GM's early successes (Section 2.1.2). However, to successfully implement this shift in the construction industry, a company would have to reduce the customization specific managerial burden that had caused the industry to shift into a mismatch zone on the product process matrix in the first place.

2.4 Inherent Constraints and Opportunities in the Mass Production of Homes

In section 2.2, the product process matrix is introduced which demonstrates the purpose of standardization and its relationship with capital equipment. Most notably, standardization allows the use of capital equipment, which increases productivity, while custom products are best produced with general purpose equipment and high skilled labor. This matrix is applied to the construction industry in section 2.3. While the literature is inconclusive, two trends in the construction industry may be caused by the relationship demonstrated in the product process matrix, namely: the widening gap in productivity between the construction and manufacturing industries over the past half-century and the difficulty in using capital equipment to increase productivity within the construction industry. If this application proves true, then from a construction process standpoint, the residential construction industry is unnecessarily inflexible and unnecessarily limits a customer's choices and options.

It has also been shown that contractors have standardized in an attempt to reduce cost. However, the industry has been unable to employ the corresponding capital equipment that would allow the dramatic productivity increases seen in manufacturing. Given this information, the product process matrix implies that the construction process has much more flexibility than mass production processes. It also implies that the construction industry has standardized, not to increase process efficiency—as seen in manufacturing, —but to reduce managerial burden. To reduce the cost of customization, contractors would have to look for managerial efficiencies and not construction process improvements. If the managerial burden could be overcome, contractors could customize with little added cost, providing a unique competitive advantage.

This section further explores a number of significant attempts to mass produce homes and develop specialized capital equipment, some stretching back almost 100 years (Snyder, 1985; Mann, 2008). While this review is not meant to be exhaustive, it highlights various difficulties in mass producing homes, including difficulties shipping homes from the capital equipment to the jobsite, difficulties shipping capital equipment to the jobsite, maintaining the volume of homes necessary to pay for large capital equipment costs, the effects of cyclical economic cycles on builders with large capital equipment costs, and quality issues. By tying the industry's struggles using capital equipment back to the product process matrix, it seems that the industry has not been standardizing due to process efficiency.

2.4.1 Catalog Homes

One of the first construction companies to recognize the advantages of mass production was Sears, Roebuck and Co. In his article "The Sears Pre-Cut," Snyder (1985) outlined their attempt at mass production. He stated that in 1908 Sears, Roebuck and Co. decided to expand their booming mail order catalog to include kit homes. These homes were ordered from a catalog that included detailed renderings and floorplans. The unique part of catalog homes was that "every piece of framing lumber—rafters, floor joists, studs, stair stringers, plates and girders—was cut to finished size at the mill and numbered. Even the interior trim was pre-cut, and the doors arrived mortised for locksets" (Snyder, 1985). Initially the idea was incredibly successful. Mann (2008) estimates that over 500,000 catalog homes were sold by over a half dozen different manufacturers.

Initially catalog homes delivered on their promise of greater efficiency, lower cost, and increased productivity. To prove this point "Sears had two identical homes built side by side, one pre-cut (catalog), the other not. The pre-cut packaged home went up in 352 carpenter man-hours, while constructing the home the ordinary old fashioned way took 583 ½ man hours." (Snyder, 1985) This equated to roughly a 40% increase in productivity. Catalog homes were successful for many years; however, the practice eventually faded in favor of traditional building practices. Mann (2008) noted that the majority of catalog home companies stopped producing during the great depression with only a few surviving until after WWII. Like all mass-produced products, they relied on large volumes of homes to maintain profitability. However, the volumes were difficult to sustain during the depression and WWII. (Snyder, 1985; Mann, 2008).

Unfortunately, catalog homes had several limiting factors. As with all mass produced homes, shipping was a major problem (Snyder, 1985). Due to the limited shipping options of the era, catalog homes needed to be built near rail-heads. This limited their ability to target rural customers and prevented traditional building practices from completely dying out. The development of power tools was surely another factor in the downfall of catalog homes. In the early 1900's, electricity was still unavailable in many areas of the nation. So traditional builders were forced to use time intensive hand tools for cutting, sawing, and drilling. Catalog homes were most effective at replacing these labor-intensive operations with more efficient processes. However, when power tools became standard, these same operations could be performed at the jobsite with similar levels of efficiency.

Regardless of catalog homes' failure in the market, some efficiencies gained were adopted into traditional building practices. Snyder (1985) identified pioneering concepts from catalog homes including an early form of drywall, asphalt shingles, and pre-mortised doors (an early form of pre-hung doors), that were eventually adopted by the construction industry. Catalog homes also introduced componentization and modularization (see section 2.5).

2.4.2 Mobile, Manufactured, and Modular Homes

One of the more interesting case studies in mass producing homes comes from the manufacturing industry. Shortly after WWII, there was a large new housing demand for the returning veterans. Due to the very limited supply of housing, some veterans began purchasing "trailer coaches," a mobile house like modern RV's, but without bathrooms and kitchens. As companies realized this demand, they began expanding their "trailer coaches" to include bathrooms and extra space. Eventually these "trailer coaches" evolved in two different directions. Some tried to maintain their mobility and became the modern mobile home. Others sought to use the factory style construction environment for a more permanent structure, and became manufactured homes (Bellis, 2013). Mobile and modular homes were unique for two reasons: first, they were the only style of home to originate as a manufacturing process, and second, they were the only type of home shipped with the majority of construction completed in a factory.

Unfortunately, manufactured homes had unique challenges that prevented their widespread adoption within the industry. In their early years, mobile and manufactured homes were developed as a low cost alternative to a traditional home, and were never manufactured to the standards of a traditional home (Irontown Homes, 2013). Many sacrifices in quality were made to make the home more affordable and easier to ship. This was an important contrast to manufacturing's transition to mass production, which increased quality while lowering price (Beamish, 1862; Ford, 2007). The decreased quality was noticed by customers and has haunted the industry for their entire history (Broad, 2013).

Another unique challenge with manufactured homes was the very stringent size limitations required for shipping on public roadways. When manufactured homes were first introduced shipping requirements limited the widths to 8 feet (Bellis, 2013). While improved roadways and legislation had increased the allowable shipping widths, each section was still limited to 14 feet 6 inch wide in most jurisdictions. This limitation had significant effects on home layout and design. The industry struggled with a reputation for boxy and unappealing homes.

In more recent years, contractors had attempted to increase the quality of modular homes (a modern term for a higher quality manufactured home). To overcome the stigma of manufactured homes and to increase quality, they had transitioned to more traditional construction methods and materials and developed a more custom design process. These homes did see some productivity improvements over traditional homes, such as with one company advertising an 8-10 week factory construction schedule compared to a typical 90-120 day schedule by comparable custom builders (Irontown Homes, 2013).

Manufactured and modular homes had some success in the industry, as well as some productivity gains. However, they had not developed and utilized the specialized capital equipment seen in the manufacturing industry, and had not seen the dramatic productivity increases common in the manufacturing industry (ElBoghdady, 2007). As seen in other examples, manufactured and modular homes struggled to improve productivity by using specialized capital equipment due to the difficulty in selling large volumes of standardized homes.

2.4.3 Pulte Home Sciences

More recently, Pulte Homes tried one of the most sophisticated attempts at mass producing homes. In the early 2000's Pulte began producing precast foundations (foundations poured in a factory, and shipped to a jobsite) (Umberger, 2002). Pulte's goal was to cut costs by $3,000 - $4,000 and reduce the building schedule by 15 days.

Pulte officials initially felt that the idea held great promise. They quickly expanded the idea from concrete foundations to include most of the building's structure and mechanical equipment (Umberger, 2002). The advantages of the mass produced home were not completely financial. ElBoghdady (2007) noted that the plant offered more precision, less waste, and fewer weather-related defects and delays. In addition, by curing the concrete in a climate-controlled process, they were able to obtain higher compressive strengths and use less concrete.

The significance of Pulte's experiment went far beyond componentizing the structure and building it off site. The significance comes from the level which they attempted to automate the construction process and increase productivity by using capital equipment. As ElBoghdady (2007) stated:

> For decades, builders have manufactured houses in factories. But the logistics of transporting manufactured, and modular homes limited the possible floor plans, and the product was generally seen as a low-end option. In many ways the methods used inside the factory were no different than those construction workers used in the field... By contract, Pulte's plant was highly automated… The climate-controlled plant allowed more precision, less waste, and fewer weather-related defects and delays.

Tying this statement back to the product process matrix shows that construction and manufacturing were subject to the same forces identified in the matrix (See section 2.2.1), namely that at higher volumes production become more efficient, less variable, and less costly because high skill labor could be replaced with equipment (Clark, 2012; Deming, 1986). While the concept initially proved promising, the factory only lasted for three years prior to being shuttered. ElBoghdady (2007) speculated that during the housing bust the company lacked the volume necessary to keep the plant open. Additionally, the housing bust caused a significant oversupply of labor, further decreasing the cost of the traditional construction method.

Jim Peterson, director of research at Pulte Homes Sciences, identified some important constraints necessary to justify the factory. He stated that the plant needed to produce 1,000 homes/year to justify its expense. In addition, the plants shipping radius was limited to 100 miles ("Pulte Ramps up Factory Component Building System," 2005). This showed that the large structural components the plant was attempting to produce were difficult to ship long distances. The 1,000 homes in a 100-mile range was unique to the Pulte plant. However, this gives a general indication of the difficulty in mass producing homes. Builder's magazine market analysis shows that in 2012 there were only 11 locations in the United States with a builder that met the necessary volume requirements in such a limited area.

2.4.4 DiVosta Homes

DiVosta Homes had a unique strategy for mass producing homes. Unlike other builders who sought to achieve mass production by building in a factory, and moving completed homes/structures to the jobsite, DiVosta Homes attempted to achieve a steady flow construction process at the jobsite. To accomplish this, they relied heavily on the manufacturing principles of Just-In-Time delivery and lean manufacturing (i.e., lean construction).

The DiVosta construction process was unique in that they identified 42 one-day construction tasks, and had separate crews assigned to each task. Every morning a crate would arrive on the driveway of the home with the exact materials needed to complete the day's tasks. Many of these materials had been prepped earlier in a warehouse. This allowed the crews to move through each home in the subdivision in a very systematic and efficient manner (Broad, 2013).

To achieve this steady flow process, DiVosta had to standardize everything. Similar to Henry Ford's "A customer can have a car painted any colour *[sic]* he wants so long as it is black" motto (Ford, 2007), each DiVosta subdivision only had one or two floor plans, no structural options, a single paint color, and identical finishes (Broad, 2013). This systematic construction process resulted in a very high-quality home with no variation.

Due to their level of standardization, DiVosta Homes was able to achieve significant productivity increases, utilize some unique levels of capital equipment, and reduce requirements for skilled labor. There were many examples of this. One simple example was producing a custom set of concrete forms that matched the wall of the house including all blockouts. These were then craned into place as a complete unit. This significantly reduced the amount of time required to form concrete walls. Another simple example was the electrical systems. In the warehouse a laborer would measure and cut every wire in the house and attach it to an electrical box and outlet prior to it being delivered to the jobsite.

While DiVosta was very successful during the housing boom, the company recently stopped using the process in favor of traditional building practices. Broad (2013) identified two reasons for this. First, their process required a significant backlog of homes to achieve the steady production process. During the recession, this backlog disappeared leaving their crews without enough homes to keep them busy. Second, they could only target "1/2 of 1%" of the market, because most people don't like living in a subdivision where their home is identical to their neighbors. As with other attempts at mass production, the level of standardization necessary to greatly increase their process efficiency was unacceptable to customers in one geographic location, and their process prohibited targeting small groups of customers over a large geographic area.

2.5 Mass Customization

Previous sections outline the dynamics involved in the standardization of products. Understanding these dynamics provides an important context for further study into efficient methods of customization. The product process matrix (Section 2.2) outlines why standardization increases productivity and reduces cost. Despite this relationship, customers still desire products which are low cost and flexible, but producing these products presents a variety of managerial and production process challenges. Regardless of these challenges, some companies have seen success developing this strategy, which can be termed "mass customization" (Dedrick and Kraemer, 2007; Duray and Milligan, 1999; Pine, 1999).

In construction, mass customization might be a misnomer. As explained in Sections 2.3 and 2.4, the construction industry has struggled to develop the highly efficient mass production processes which manufacturers were trying to adapt. However, there are benefits to identifying techniques in which manufacturers have increased both flexibility and efficiency. One such technique is a parametric design process that can modify product designs quickly and efficiently, while reducing the impact these modifications have on other management processes (Jiao and Tseng, 1999). Such techniques could reduce the managerial burden that has caused the residential construction industry to standardize.

2.5.1 Mass Customization Strategies

The marketing strategy of a mass customizer differs somewhat from that of a traditional mass producer. As outlined in Section 2.1.2, mass producers targeted individual customer preferences by identifying small groups of similar customers over a large geographic area. The demand for each of these customer groups was forecast, produced, and pushed onto the market. These increasingly fragmented markets could cause difficulties with forecasting and marketing to customers. As Pine, Peppers, and Rogers (2010) stated, "to handle their increasingly turbulent and fragmented markets, [managers] try to churn out a much greater variety of goods and services and to target ever finer market segments with more tailored advertising messages. But these managers only end up bombarding their customers with too many choices." They later explain that mass customizers differed by individually customizing goods to unique customers.

The individually customized one on one marketing strategy required a new manufacturing methodology. Traditional mass production required forecasting demand for each individual product, including all its permutation of options, and then "pushing" them through the manufacturing process and into the market. Toyota, on the other hand, developed a unique "pull-based" manufacturing process (The Toyota Production System or TPS) where multiple car models could be manufactured using the same production system (Crowley, 1998; Cuperus, 2003). The TPS had several unique advantages. First, custom products had varying complexities that affected the manufacturing process time. The TPS automatically identified the current bottleneck and transitioned resources to clear it. In addition, by identifying product demand prior to production, the TPS reduced or eliminated forecasting errors. However, this also required a backlog of work to keep the manufacturing capabilities fully utilized.

In construction, there are several important takeaways from these semicustom business strategies. The advantage of the TPS marketing and manufacturing strategies is the large steady flow of production. This avoids a cycle of straining and underutilizing resources that could be common in a custom production environment. Construction requires a slightly different process to steady the flow of construction. Best practices involve creating a start schedule, where construction of new homes begins on consistent and predictable intervals. Schedules are standardized across all units, ensuring that trades have a consistent and steady flow of work. If necessary, crew sizes are adapted to maintain the schedule. This ensures that trades have a consistent and predictable backlog of work (Sedam, 2011b).

Mass customization also requires efficient ways to produce a nonstandard product. The product process matrix (Section 2.2.2) shows that it is difficult to improve process efficiency when products are not standardized. Some authors recognized these limitations and developed ways to customize within those limitations. They primarily accomplished this by isolating elements of a complete product and standardizing how the subcomponent attached to the main product. This modularity allowed elements of the completed product to be customized while maintaining the traditional manufacturing requirements (Duray, 2002; Pine, 1999).

Others took a more innovative approach to mass customization. Jiao (1998), Jiao and Tseng (1999), and Roach, Cox, and Sorensen (2005) suggested developing a product family with a set of core common features. This included identifying the generic product type or taxonomy and outlining its building blocks, components, configuration rules, and economic cost/value. The customer was allowed the flexibility to customize the product within these bounds. The manufacturer could then develop a flexible manufacturing process to produce products within those constraints. By setting the product's constraints and bounds prior to the customer's order, a manufacturer could identify elements that required a high degree of standardization to achieve efficient production. By limiting choice in those areas, and allowing more flexibility in others, a manufacturer could allow a semicustom design while maintaining efficiency. This form of mass customization was termed product family architecture.

Each method of mass customization was common in the residential construction industry. Structural elements had developed using generally applicable and stretchable assemblies. For example, wood framing methods had been standardized into generally applicable assemblies. Building codes had responded to these assemblies by developing generic rules regarding their use. Manufacturers adapted their products to work with and in those assemblies, and trades specialized in the installation of those assemblies. These elements together allow home structures to be uniquely customizable. For example, one national builder maintained 2,200 unique floor plans (Kerwin, 2005).

Finish options followed the method of customization advocated by Duray (2002). Connection requirements had been standardized for most finishes in a home. For example, light fixtures all attached to a standard 4 inch electrical box, plumbing faucets had standardized around three connection requirements (single hole, 4 inch, and 8 inch three-hole pattern), cabinets were commonly standardized to 3 inch increments, and appliances came in standardized sizes. These standard connections made changes to finishes very easy to achieve.

2.5.2 Mass Customization in Preconstruction

Contrasted to the construction process's high potential for customization, the preconstruction process has many challenges that have led to standardization. Using current systems, many changes in one area of the preconstruction process cascade into other elements of preconstruction. This lack of isolation has caused small changes, or customizations to overload the preconstruction process (Bousquin, 2015b). In some instances, the general way in which many assemblies were defined led to waste and overengineering, or conflicted with purchasing best practices (Sedam, 2011a; Sedam, 2017). Many Building Information Modeling (BIM) systems also lacked the detail necessary to perform an accurate, or complete cost analysis (Sattineni and Bradford, 2011).

In residential construction, current option pricing systems do a poor job of isolating the effect structural changes have on finish options. Estimating systems appear to follow two paths. Some require a full list of selections before estimating the house, making it difficult for perform a cost analysis on the price of options. Others provide customers with finish option pricing, but the absence of a clearly defined structure forces every permutation of structural and finish options to be priced—while custom structural options lack finish option pricing all together. Many builders who have attempted this strategy discovered that the resulting "option overload" quickly became unmanageable, and scaled back customization to make processes more efficient (Bousquin, 2015b).

A foundational element of product family architecture is a parametric design process (termed BIM in the construction industry) (Autodesk, 2007; Roach, Cox, and Sorensen, 2005). These systems rely on intelligent objects to automate parts of the design and engineering process. For example, BIM systems can notify if windows encroach in the header space, adjust floor joist layouts for a bonus room, and automatically add electrical switches and doors when changes are made to the model (Sedam, 2011d). In a mass customization environment, BIM systems should also integrate with costing, scheduling and other business processes. As Roach, Cox, and Sorensen (2005) state,

> In addition to thoroughly understanding the best practices in design of the product class, [mass customizers] must be able to generalize the process so that it will apply to any member of the class. Further, they must be able to understand principles of reuse and modularity that are common to software engineering. Finally, they must understand how the design process is interrelated with other business processes of the company.

While integrating design and business processes is possible in theory, actual business practices have been much messier. In a three-part series, Sedam highlighted the capabilities of BIM in areas such as informing intelligent design, integrating with costing and scheduling, removing waste, collaborating with trades, and helping customers visualize products. However, the he also talked about the substantial amount of data that must be generated and stored in the model for it to operate correctly. He highlighted several examples of companies who had seen vast improvements to their processes but noted the implementation of those changes had taken a year or more to implement and had many pitfalls. The experience with implementing BIM was often painful (Sedam, 2011c; Sedam, 2011d; Sedam, 2011e).

Much of the difficulty regarding BIM can be traced to miscommunication and mismatches between BIM and established business practices. Roach, Cox, and Sorensen (2005) identified four elements necessary for parametric modeling to work well with mass customization including: generic product type or taxonomy, building blocks, configuration rules, and economic evaluation. These need to be defined prior to BIM modeling, as they would influence how the model is drafted. However, achieving this definition was difficult. Construction processes were not stagnant, but under a constant state of flux. Building blocks and configuration rules changed as new products were introduced, better building practices were established, and codes were updated.

Successful implementation of a BIM system requires that the model is easily adapted to changes in the construction process. The process needs the ability to adapt to changes in codes, products, and assemblies without requiring dozens of plans to be redrafted.

2.5.3 Mass Customization Strategy for Preconstruction

While Construction literature contained numerous references to the challenges customization posed for preconstruction, strategies for customizing effectively were sparse. There was a dichotomy between construction marketing literature, which advocated the advantages of customization (Bady, 2018), and construction business management literature, which advocated streamlined processes with few options (Bousquin, 2015b).

The first criteria to successfully mass customize in preconstruction is identifying the level of customization that a company would offer. While this seems simple on the surface, many strategies to successfully mass customize conflict with strategies in other areas of preconstruction. Sedam (2017) highlighted several examples of how this could take place. In one, a builder was framing every exterior wall opening with 2x12 headers, even though the flooring system above carried the load from the roof and second story. He estimated this overengineering cost $1,000 per house.

There were several ways the company could handle this challenge. The difficulty was not the challenge itself but ensuring the company's strategy to handle these situations was consistent. For example, the company could accept the overengineering as a cost of customization, could limit structural changes to non-load bearing walls, or could require a structural analysis of each custom plan. Each of these strategies had ramifications on the cost of the product, the responsiveness to the customer, and the ease with which the customization was communicated. However, if a strategy was not defined and adhered to, the preconstruction team became overwhelmed as the pendulum swung between these completing strategies.

The effect of customization reverberated in other areas of preconstruction as well. Sattineni and Bradford (2011) surveyed US construction companies and determined that only 15-22% of BIM models contained the information necessary to perform an accurate takeoff. This was partially due to the correlation between purchasing and estimating. The level of the estimate, and thereby the level of modeling, was influenced by how the contractor purchased materials (turnkey or direct from suppliers), the level of detail in a trade's pay scope, and the assemblies that a contractor offered. To successfully use a BIM model to estimate, the key measures the model generates must be intimately aligned with the methods a contractor uses to purchase supplies and labor. Just drafting a model in a BIM system is insufficient to ensure the model could create an accurate estimate. The model must be designed in a way that ensures it is developed with the information necessary to estimate.

Creating the link between BIM and estimating/purchasing is possible in theory but has been difficult in practice (Kraus, Watt, and Larson, 2007; Nassar, 2012; Sedam, 2011e). This is partially due to the enormous amount of additional work necessary to add this data into the model. Despite the additional work, Sedam still viewed it as necessary to ensure an accurate BIM estimate (Sedam, 2011d). While creating such detail could resolve issues with estimating, it also creates additional difficulties in a mass custom environment (i.e. increased time to draft the model, increased time to model custom requests, changes to assemblies or vendors requiring changes to the model, etc.).

Simplifying the link between BIM and estimating/purchasing is possible. However, it would require a simplified pay structure. Many phases would require turnkey pricing, due to the difficulty in estimating some materials. In addition, lean construction and many purchasing negotiation techniques require a high degree of detail (Callahan, 2015; Sedam, 2011a; Sedam, 2011f; Sedam, 2017). Simplifying this link could increase cost and would curtail these strategies.

As noted earlier, mass customization is a highly desirable strategy for many contractors in the residential construction industry. However, there are many pitfalls to developing such a strategy. The literature lacked guidance on how contractors could determine an ideal level of customization, the cost implications of that strategy, and how to align their marketing, purchasing, estimating, and BIM strategies. Given the difficulty required to implement these strategies, contractors need clear guidance before the implantation process begins. The interest in this topic shows the need for this research into those areas.

3 METHODOLOGY

As noted in Chapter 2, customization causes significant challenges. This has forced most builders to substantially reduce customization levels as they grow. However, contractors need the ability to customize, because residential homebuyers demand a high degree of personalization. Intuition would argue construction processes are responsible for the decreased flexibility. However, as noted in Section 2.5, the preconstruction processes (e.g. estimating, purchasing, sales option pricing, etc.) may play a greater role in the lack of flexibility.

The conflict between a customer's desire for flexibility and a producer's desire to reduce cost and complexity through standardization is not unique to the construction industry. There is a large body of literature within the manufacturing industry on mass customization (i.e. the ability to allow product flexibility while maintaining the efficiency of mass production). Section 2.5 outlines several strategies for mass customization, including modularity and a parametric design process. This thesis explores methods to apply these mass customization strategies to the residential preconstruction process. The success of these strategies in other areas suggests their application could increase the flexibility of residential contractors. In this research, a small group of industry professionals were interviewed using the Delphi Method. Through their responses, strategies for increasing customization were identified. The purpose of this research is to establish a systematic approach for increasing customization while maintaining critical process controls.

3.1 Research Structure

The limits or bounds of existing research were identified through a literature review. These bounds play an important role in determining the methodology for further research. Merriam and Tisdell (2015) note that the two branches of research are divided on their purpose. Qualitative research seeks to push or expand the body of knowledge by developing a theory on how "the world" operates. Quantitative research seeks to test the veracity of a theory. It was demonstrated, through the literature review, that theories for applying mass customization principles to residential preconstruction processes need to be developed. This would be best accomplished through a qualitative research methodology using the Delphi Method. Later research could test these theories using quantitative means.

The literature review showed that some producers and manufacturers have increased process flexibility through mass customization. It also outlined key design and process changes that served as guidelines for implementing mass customization. These include product family architecture using a parametric design process and modularization (Duray, Ward, Milligan, 2000; Pine, 1999; Roach, Cox, and Sorensen, 2005). The principles outlined in these processes are broadly applicable, which implies that construction specific testing is warranted.

Testing mass customization in the construction industry presented some challenges. While the principles necessary for mass customization were broadly defined in the literature, little was written on a construction industry specific application. An analysis of the sales, design, estimating, purchasing, and construction departments needed to be performed, identifying areas where customization hurts process efficiency. Identifying bottlenecks would allow process improvements to be developed using mass customization principles.

Another challenge was the significant investment in time, money, and resources necessary to test these theories using quantitative means. Quantitative testing required a functioning construction process which was cost prohibitive. Due to these constraints, a qualitative study (i.e. interviewing industry professionals through the Delphi Method) was the best avenue to develop a preconstruction specific mass customization strategy. A qualitative study also serves as a platform for quantitative testing.

3.2 Data Collection

Data collection was performed using the Delphi Method. The Delphi Method is an iterative interview process for achieving reliable consensus of opinion from experts (Sourani and Sohail, 2015). In this research, two rounds of semi-structured interviews were conducted with residential home building industry professionals. These interviews identified existing preconstruction processes, benefits of those processes, how the processes could be adapted for mass customization, and using BIM to aid customization. After the first round of interviews was completed, the information was gathered, collected, and analyzed for correlations between the expert's responses. These correlations were used to model a systematic process for improved flexibility in residential construction. The model process was sent to these experts for review and follow-up interviews were conducted. This provided an opportunity for the experts to review, critique, and refine the process; helped identify the effects of the proposed process; and gave experts an opportunity to react to the responses of others.

In their article on opinion based research in the construction industry, Sillars and Hallowell (2009) highlight the numerous benefits of this methodology. They state that Delphi Method is ideal when the respondents need high qualifications, and/or have limited qualified applicants. Being geographically dispersed does not pose an issue to this type of research. In addition, the Delphi Method reduces bias from highly qualified or vocal respondents (Sourani and Sohail, 2015).

The Delphi Method places larger time burdens on both the researcher and the respondents. This time burden was lessened by having a small core group of researchers develop the process (Skulmoski, Hartman, and Krahn, 2007).

Merriam and Tisdell (2015) clarify the best structure for interview questions. Their research places interview questions on a continuum from completely unstructured (open-ended, flexible, and conversational) to highly structured (wording and order is predetermined). They note the degree of uncertainty in the phenomenon at the time of interview should guide the questions structure. All questions in this study were semi-structured. This provided direction to the study, ensured critical points were covered, while allowing flexibility to follow ideas/tangents and learn from the expert's collective experience.

3.2.1 Expert Selection and Qualifications

In this study, experts were defined as directors, managers, or other personnel who commonly use, or helped develop, the systems and processes by which new products are developed, defined, bid, estimated, and constructed within their residential construction company. Purchasing manager or estimating manager were the most common titles for these experts. The target expert had worked in the residential construction industry for ten to twenty years, had at least five years professional experience in construction purchasing or estimating, and had experience with customization in preconstruction.

A national Builder 20 group was initially selected as a potential research pool because it provided experts with requisite qualifications and a broad geographic dispersion. Others were added based on additional recommendations from construction professionals familiar with research requirements. Prior to the interviews, the definition of expert was explained to an upper level manager at the company and the manager then selected the person best suited for this study. Due to the experts' level of experience and broad geographic dispersion, the researchers feel that a similar study would achieve similar results. Because many experts were members of the same national Builder 20 group, it could be considered a limitation of this study. However, the researchers do not feel this connection had major influences on this study because participating experts who were outside the Builder 20 group had similar conclusions, and the Builder 20 group was representative of the industry at large.

3.2.2 First Round Interview Questions

In the first round of interviews, ten residential construction industry experts were interviewed. Nine experts were purchasing managers, estimating managers or owners who worked for builders ranging in size from under 40 homes per year to over ten thousand homes/year. The last expert had experience in drafting and construction software and was selected to provide a more well-rounded understanding of the preconstruction process. The experts had experience in a broad range of markets including: Alabama, Arizona, California, Florida, Idaho, Nevada, North Carolina,

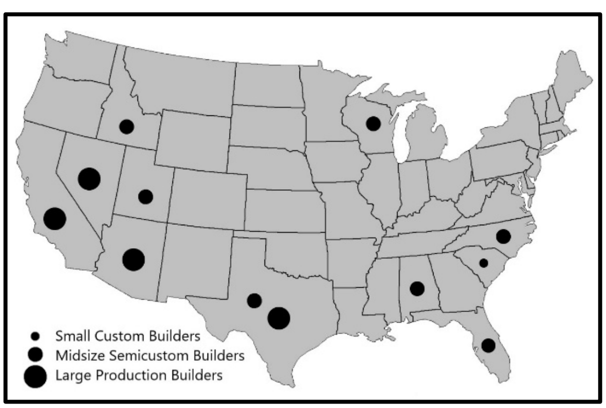

Figure 3.1: First-Round Interview Locations

South Carolina, Texas, Utah, and Wisconsin. Some experts covered multiple locations. (See Figure 3.1).

The following questions delineate the overall structure and direction for the first-round interviews. In line with the semi-structured format, the researcher had flexibility to adjust the wording, and order of the questions. When appropriate, follow up questions were asked to ensure ideas and thoughts were captured completely and accurately. The interview structure provided a conversational tone, which afforded experts opportunities to voice opinions and tangent ideas, while ensuring focus and direction.

- Briefly describe yourself, your company, and your role at the company.
- Assume you had 100 customers this year who wanted to make substantial custom changes to your plans. Where would your current system gum up? (e.g. sales pricing, ordering materials, estimating, turnaround time, overhead, etc.)
- Describe the process for new product development, starting at conceptual design through completion.
    - What steps are in that process?
        - Anticipated Steps
            - Purchase Land, Develop Lot, Preliminary Feasibility Study of Target Market
            - Preliminary Design, Review, and Preliminary Budget
            - Finalize Feasibility Study
            - Working Drawings, including Options
            - Bidding and Contract Negotiation
            - Set Sales Prices/Margins

        - Build Models
        - Grand Opening
        - Construction
    - How has this process reduced waste, and increased efficiency?
    - Where is this process inflexible?
    - Do you use BIM in this process?
- How do you test and introduce new products or assemblies in your homes?
    - Does this process vary based on the complexity of the assembly?
- When you design a new home. How do you differentiate between the new product and existing products?
    - What stays the same between all products?
    - What varies between products?
    - What varies by series?
- (Setup to Question) There are many examples of companies in other industries offering customers increased choice through mass customization. These companies define products differently, to achieve flexibility without destroying their process. They utilize two methods to define a product generically, so a broad range of products can use a single definition and process.
    - Componentization:
        - Example: At McDonalds® you purchase a predefined product (Big Mac, Angus Mushroom and Swiss). The burger is the same for all customers. However, Subway® defines their product as a group of interchangeable components. At Subway® you choose the meat

(cold cut combo, oven roasted turkey breast), and then choose from a variety of preselected components (bread type, toasted, cheese, veggies, sauces, salt, etc.). Through interchangeable components Subway® produces a much greater variety of sandwiches.

  - Product Family Architecture:
    - This method defines a process which can build one product in a range of sizes. For example, Anderson Windows® builds set window styles (e.g. 100 Series, 200 Series, 400 Series, A-Series, E-Series). These series have set manufacturing processes and components. Because their system understands how these series are manufactured, it can automatically generate quotations, manufacturing specifications, cut sheets, etc. for custom sized windows in a few seconds.

- Current processes define new homes as one inflexible product with an array of options. Could you define your product as a group of assemblies that work together?
  - How would this affect the home building process?
  - What systems/processes would need to be developed?
  - Could a high degree of efficiency, a low degree of waste/defects, and an accurate schedule be maintained?
- How would automatically generating quantities using BIM be useful in this process?

- In this environment, how could trade contracts be structured so there is trust and certainty in the payment amount?

3.2.3 Second Round Proposed Process

During the first-round interviews, the experts highlighted how uncertainty in the residential construction industry exponentially increased workloads. These results are covered in detail in Section 4.1, but are briefly explained here since they influenced the second-round interviews. This uncertainty problem was multifaceted and manifested in six distinct areas: communication with the customer, communication with trades, the bidding process, including upgradable materials in base house assemblies, finish option pricing for custom structural options, and exponential finish option growth. The significant challenges these problems presented caused most builders to significantly reduce customization as they grew. Many experts who heavily customized had processes which simplified customization in preconstruction. However, some concerns were related to software and systems, and outside expert's control.

The purchasing/estimating processes were key for a successful customization strategy. In an environment with a high degree of uncertainty, trades needed clear communication. Estimators needed accurate information to quickly respond to customer's requests. The estimating processes needed to be simple, efficient, cost conscious, and generally applicable. This was achieved through the purchasing process. Experts negotiated unit pricing which was simple enough for efficient estimating but detailed enough to control cost. In addition, they controlled the pay structure for each cost code. This ensured a new trade did not invalidate the estimating process.

Unit pricing and controlling the pay structure also simplified communication with trades. Unit pricing limited required communication (i.e. estimators could price options without a bidding process). Once custom changes were finalized, trades could expect communication in a consistent and reliable manner (plans, specifications, and purchase orders).

When necessary, a meeting between the estimator, drafter, and customer simplified communication with the customer. This ensured custom requests were completely understood and documented. In addition, these employees were best positioned to understand construction implications of customer requests.

Many software systems significantly limited modularity in preconstruction. This was a significant concern among the experts. There were several areas where this occurred including: requirements to include upgradable material in base house assemblies, custom structural options lacking finish option pricing, and exponential finish option growth.

Many software systems were unable to calculate structural option pricing from multiple options. Calculating the base house selling price was greatly simplified when it was tied to one estimate. However, this process had significant ramifications in estimating. If upgradable material was included in base house estimates, then any structural options must first remove that material from the base house. This increased the time necessary for estimating, was confusing, and had a high potential for errors.

Software systems also lacked the ability to price finish options at point of sale. However, there was a high degree of uncertainty in finish option pricing until the layout and structure were finalized. This caused multiple challenges. Custom structural options lacked finish option pricing. While finish option pricing grew exponentially with builder specified options.

Based on the results of round one interviews, there were several proposed changes to the preconstruction process that were generated. It was anticipated that, negotiating generic assembly level unit pricing with trades, building an estimating system which understood those assemblies, negotiating finishes into tiers, storing finishes generically in structural options, removing upgradable material from base house assemblies, and automating the structural and finish option pricing at point of sale would greatly increase the flexibility of the preconstruction process.

The proposed process had limitations; it was expected that assembly level pricing would reduce cost controls, purchasing negotiation techniques, and lean construction processes. The significance of those effects warranted further study. Additional research was also needed to establish effective methods for interdepartmental communication, and communication with trades. This process needed clear customization limits; however, such limits can be difficult to establish. Best practices for communicating customization limits needed to be established. These questions were further studied in the second-round interviews (Sections 3.2.4 and 4.2).

3.2.4 Second Round Interview Questions

In the second round, six residential construction industry experts were interviewed. Five these experts were purchasing agents, purchasing managers, or estimating managers who worked for builders ranging in size from one hundred homes/year to over ten thousand homes/year. The last expert was a sales option coordinator who had experience with drafting, BIM, and Sales Option setup. Two of the experts in the second-round interviews had also participated in the first-round interviews. The remaining experts from the first round were unavailable during this round of interviews. These experts had experience in a broad range of markets including: Alabama, Colorado, Florida, Idaho, Nevada, North Carolina, and Utah. Some experts covered multiple locations. (See Figure 3.2).

The second-round interview questions were semi-structured in nature. As in the first round, the researcher had flexibility to adjust the wording and order of the questions. Follow up questions were asked as appropriate to ensure opinions and ideas were completely and accurately captured.

Appendix A contains process slides which were used during the interview process. These slides helped explain the problems identified during the first round, how mass customization aids

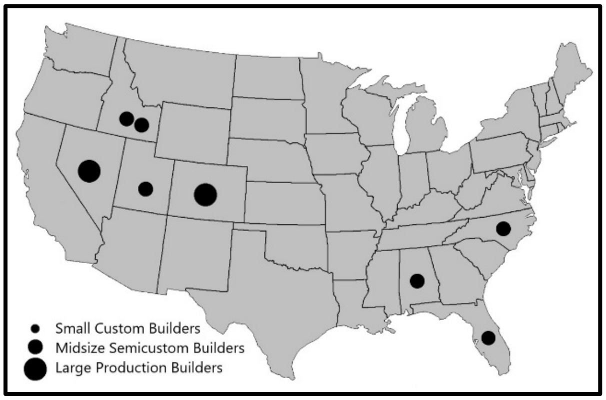

Figure 3.2: Second-Round Interview Locations

customization, and the proposed process which was developed during the first round. The order and context of these slides is explained in the interview questions below.

- (Interview Setup) This study seeks to provide increased ability for customization in the residential preconstruction process through application of mass customization principles. This is the second round of interviews. During the first round, industry experts were interviewed to identify bottlenecks in the residential preconstruction process when customization was introduced, processes to overcome those bottlenecks, and the impact of those processes.

  After the first round a process was developed to allow increased customization through the application of mass customization principles. This round of interviews seeks to validate that process and identify the processes effects.

- Floor plan slides 1 – 4 were shown (See Appendix A.1 – A.4).
    - How would you structure the cabinet and countertop options on this plan in your sales option pricing database?
- Cabinet price slide was shown (See Appendix A.5).
    - Is this an accurate representation of the sale pricing structure for these options?
- Current process, mass customization process, and web diagram were shown (See Appendix A.6-A.9).
    - During my literature review, I came across a theory on effective customization. This study pulls this theory from a manufacturing realm and applies it to the residential preconstruction process. The theory states customization in difficult, because a change in one area cascades into another area. This uncertainty causes exponential growth in processes and products.

      You can combat exponential growth by isolating a part of a product or process and standardize the size and connection requirements. For example, consider the difficulty customizing a light fixture in your home vs. the headlight on your car. A light fixture is very easy to customize because it attaches to a 4 inch round electrical box, and a 110 V wire. Redesigning the headlight on your car would require changing the front bumper, side panel, grill, and hood of the car. In these examples, the light fixture is easy to customize because it is modular, isolating the change. The headlight is difficult to customize because any change cascades into multiple other elements in the car.

The same theory can apply to processes as well. In the kitchen example (Section A.1 – A.5), customizing cabinet layouts is difficult because any change to the layout cascades into multiple finish options. Each change exponentially grows, until the work is unmanageable. A truly custom change is also difficult, because of the uncertainty with finish options.

During the first round, many experts felt one significant challenge with customization was a lack of isolation in sales option pricing. The kitchen option pricing at the start is an example of this. Other examples include the need to contact trades to price custom option requests, the need to remove standard items from a base house estimate to estimate options, and uncertainty pricing tiers for finish options.

  - Does this accurately depict the difficulty customizing in the preconstruction process?

- Proposed process slide was shown (Appendix A.10 – A.14).
  - Using responses from the first-round interviews, a process to increase modularity and flexibility in the preconstruction process was developed (Section 3.2.3). At this point in the research, the proposed process changes included six elements, which affect the purchasing/estimating process, as well as construction software design. These elements include: negotiating generic assembly level unit pricing with trades, building an estimating system which understands those assemblies, negotiating finishes into tiers,

storing finishes generically in structural options, removing upgradable material from base house assemblies, and automating the structural and finish option pricing at point of sale.

  - How do you feel the proposed process would affect the residential preconstruction process in a highly custom environment?

During the first-round interviews, it was anticipated the proposed process would have significant effects on the preconstruction process, especially trade negotiations. The remaining questions focus on the effects of this process.

- Can you create assemblies for all major areas of construction, or are there elements that are difficult to estimate that generically?
- What effect would an assembly estimating have on cost control strategies? (lean construction, purchasing negotiation techniques, etc.)
- What trades are difficult to move to unit pricing?
- How do you negotiate effectively when unit pricing is not tied to the materials used on the job? (Plumbing Layout)
- How do you control costs when you bid the job after the trade knows they have the work (trusses, electrical, flooring)?
- When you are negotiating, can you define the pay structure the trade will use, or will the trade want their own pay structure?
- Would you be nervous to automate option pricing?
  - What elements would make you nervous?
  - What would make you comfortable to use the system?

- How does your company decide the level of customization they offer?
    - Who has the authority to reject a custom price request?
- How do you communicate to sales/customer which custom changes you will entertain, and which you will reject?

3.3 Data Analysis

To aid in the data analysis, the interviews were transcribed. After the transcription, the panelist's responses were analyzed for difficulties associated with customization, processes to increase customization and flexibility, areas where mass customization processes could be implemented, and unique processes or ideas. It was determined that these areas best aligned with the purposes of this study.

While analyzing the data, the degree of consensus guided researchers to important topics, and industry trends. It was assumed that challenges voiced by multiple respondents represent industry trends, while challenges voiced by few respondents or dismissed by many respondents were localized challenges. This study focused on industry trends and significant challenges. Challenges that did not meet these criteria were dismissed from further research.

The researchers also looked for solutions to these challenges. With many challenges, multiple solutions were presented. Based on experts' responses, researchers determined which solutions were the most efficient and effective. If the data was unclear, multiple solutions were presented to experts in the second-round interviews.

When presented, many experts recognized principles from mass customization theory. Many presented processes where mass customization principles were practiced. These experiences were especially helpful, because it helped experts make connections, and propose theoretical solutions to customization challenges in residential preconstruction. During the second round, theoretical solutions were presented to the complete panel. Many of these theoretical solutions were validated by experts who had seen the proposed process or based on the panel's expertise as a whole.

During the second-round interviews, there was a high degree of consensus among the experts. This provided confidence in the proposed process and conclusions.

3.4 Pilot Study

Prior to each round, a pilot study was conducted with one builder in the interview group. The purpose of the pilot study was ensuring that questions were well thought-out and easy to understand. It also helped identify gaps in the questions. The results from the pilot study were used to refine the questions for the primary study. In addition, the results from the pilot study were added to the results from the primary study for analysis prior to the second-round interviews and final analysis.

4 RESULTS

4.1 First Round Interviews

In the first round of interviews ten residential construction industry experts were interviewed. Nine experts were purchasing managers, estimating managers, or owners who worked for builders ranging in size from under 40 homes per year to over ten thousand homes per year. The last expert had experience in drafting and construction software and was selected to provide a more well-rounded understanding of the preconstruction process.

The experts' responses were easiest to understand when divided into three distinct subsets (determined by number of homes constructed). Other ancillary effects (i.e. market type, geographic location, and construction processes) also affected these subsets. In general, experts from larger construction companies offered substantially less customization and felt it had a substantially larger impact on their processes. Experts from small construction companies felt customization was relatively easy to offer, and necessary to sell homes. Gaps were left between subsets to represent transition periods. During these transitions, operational stresses forced companies to develop new and adapt existing processes.

Each subset was defined by a shared group of business processes and market forces that allowed success within a range of home volumes. Growth inside a subset appeared relatively easy to maintain, while growth from one subset to the next subset was far more difficult. Changing subsets entailed a change in business processes, which decreased the level of customization the builder could offer. The change in business processes strained the company at the same time decreased customization strained relationships with their customer base.

Among experts in the midsize builder subset, semicustom building was viewed as a key element of success. Many operated in smaller markets and needed to target a broad range of customers to maintain volume. However, semicustom building also presented challenges that were not adequately addressed by the industry. Based on their responses, improving the semicustom build process would provide three main benefits. It would ease the transition of a builder trying to grow from a small custom builder, to a midsized semicustom builder, it would allow them to sell more homes in smaller markets, and it would increase the competitive advantage of midsized builders against large production builders.

Semicustom builders had developed many processes to enable semicustom construction. However, significant challenges still existed. These experts theorized how mass customization principles could increase flexibility in the residential preconstruction process. Using their input, a process was developed for mass customization in preconstruction (section 3.2.3). The challenges they identified, and their proposed solutions are detailed in section 4.1.4.

4.1.1 Large Production Builders

The first subset of experts worked for companies building over 500 homes per year. There were two experts solidly in this subset, and a third transitioning between the midsize and largest contractor group. This group offered almost no customization other than options and finishes the builder had preselected. One expert stated the most complicated custom request they had fulfilled was changing one 16 foot garage door into two 8 foot garage doors. He was surprised there were contractors who would make custom changes in a production homebuilding environment. Another specified they were legally obligated to make ADA changes, but allowed scant customization outside of those requirements.

Builder specified types of customization (i.e. number of floor plans offered in a community, structural options available on those plans, and finishes offered in the design studio) were also sharply curtailed. Companies in this group were highly focused and had a strong understanding of their market. They knew what options would sell and removed options that sold poorly. Operating in large metropolitan markets compounded this effect by increasing the number of likeminded customers. This allowed contractors to narrow their customer profile in each subdivision.

Large Builders' ability to reduce customization was tied to an unprecedented understanding of the markets they served. One expert stated that prior to purchasing a piece of property, they understood which customers would purchase the homes, the size of that customer base, how fast the community would sell out, and the floorplans and options those customers were seeking. Builders' gathered this data from analyzing large numbers of past sales and dedicating significant resources. One builder mocked up life-size floorplans and conducted focus groups with over a thousand participants (Kempner, 2015). Due to the resources involved, gaining the same level of insight was impossible for smaller builders.

The market insight of large builders had important implications on their processes. Understanding product positioning prior to land development allowed builders to minimize lot frontage and maximize utilization to a greater degree. Understanding sales rates allowed even-flow scheduling. Simplified plans increased the benefits of lean construction, purchasing negotiation techniques, and simplified communication. The benefits varied, but reduced customization was providing important benefits.

Due to the resources involved, it was near impossible for midsize builders to gather the same level of market research. However, some resulting processes were still essential. Ironically, semi-custom building allowed midsize builders to mimic some of the processes large builders gained through standardization. This idea is explored in greater depth in Section 4.1.2.

There were other possible influences on large builders' trend towards standardization. It was previously noted that large metropolitan areas increased the number of like-minded customers, allowing increased standardization. However, location may have influenced other customization trends in ways this study was unequipped to verify. These experts had limited experience outside large southern metropolitan areas in California, Nevada, Arizona, Texas, Georgia, and Florida. Among these locations there were other coinciding factors including building regulation, weather, customer's attitudes, etc.

Variations in foundation type may also have influenced these experts' attitude towards customization. Specifically, southern markets used slab on grade foundation assemblies. Land topography was typically handled during development. In northern markets, foundation walls were required for frost protection, and topography was handled through foundation steps. This change required northern builders and northern municipalities to develop processes for structural foundation changes. The presence or absence of these processes may have influenced areas where customization was successful.

Regional differences in the municipality permitting process also influenced a contractor's ability to customize in two ways. In general, larger municipalities had a more rigorous permitting process. This increased the difficulty for obtaining permits on custom plans. Additionally, some large municipalities performed a structural, mechanical, and architectural review of the master plan set and all options during the community development. This review simplified, shortened, or eliminated the job-specific permitting process on production homes. If a job-specific plan set had custom changes, a more detailed permitting process was required. In a high-volume environment, these changes had significant impacts on a contractor's schedule and profitability.

Construction processes were only cited as a cause for decreased customization in limited circumstances. Among the experts, communication was the primary concern, particularly when the change affected multiple trades. Various examples were cited where miscommunication caused waste, delays, and added expense. Late changes also caused increased difficulty and mistakes. This study was unable to identify if the limited concern with construction process was related to their limited field experience or validated the flexibility of construction processes (See Section 2.3).

Panelized construction was another process concern. One expert stated that framing changes were difficult to communicate to their panel supplier and had significant effects on their operation. However, the other respondents had limited experience with panelized construction. The limited results made strong conclusions difficult. However, the product process matrix would have anticipated difficulties with panelization in a custom environment (See Sections 2.2 and 2.3).

4.1.2 Midsize Semicustom Builders

The next subset of experts worked for contractors building 80-300 homes per year. This group mirrored production builders in many aspects and processes. For example, all contractors in this group maintained prepriced and optioned master plan sets, operated a design studio, and steadied their construction process through a start schedule. These elements enabled contractors to maintain essential production home building practices (simplified sales process with upfront pricing, providing trades steady work, segregated departmental responsibilities, etc.).

While midsize builders maintained essential production home building practices, there were key differences. Primarily, these contractors operated in much smaller markets, which drove their attitude towards customization. The owners and sales teams (as related through the experts) felt customization was an important competitive advantage. By allowing custom changes outside their master plan sets, these companies could target a broader range of customers. This was essential to maintaining volume in the small markets where they operated.

These companies' owners felt their reputation for responsiveness to customers' wants and needs was crucial to their community rapport. Refusing to customize would endanger that reputation. One home builder's president stated (as quoted by the purchasing manager),

> We are a builder that doesn't ever want to lose its soul; meaning, the personal touch that everyone's home… deserves. [Building a home] is a personal care. We care about the quality of the product and our reputation, and we also care about the customer. That is something we don't want to lose in rigid production process.

There was room for debate on the necessity of customization. One expert noted increased growth had come by substantially increasing the number of spec homes they constructed—which had little to no customization. Despite this debate, the fear of lost reputation was real, and cannot be understated. That fear made reduced customization very difficult or impossible.

The experts' customization views were heavily dependent on the practicality of their customization process. In most instances, the customization process was cumbersome. This caused their views to diverge dramatically from company owners and sales teams. Feeling customization was an unavoidable evil, which was difficult to implement successfully, was commonly expressed. The experts also felt that the challenges with customization were not well understood. In many instances, owners' operational experience with customization was limited to the small builder stage (Section 4.1.3). Small builders have a substantially different process, which makes customization much easier.

The most successful customization experts still recognized the difficulty with customization. However, their depth of experience provided insight into managing these challenges. They had very specific requirements on how trade pricing was structured. This ensured the information they needed was on hand. Finding trade partners who would work within their system constraints was also significantly more important than lowest cost. These processes are explored in greater depth in Section 4.1.4.

Section 4.1.1 noted that midsized builders used semicustom building to lessen production builders' marketing competitive advantage, and mimic production home building processes. Production home building changed preconstruction and construction processes in ways that greatly increased company overhead. Starting at sales, production home builders pre-priced master plan sets and options. This required model homes for structural demonstrations, a design studio for finishes, upfront drafting, upfront purchase negotiations, and upfront estimating. These changes provided many benefits including: simplified sales process through one stop shopping and upfront pricing; consistency with schedules, processes, and trades; and better cost controls.

While these changes were beneficial, they resulted in large fixed overhead expenditures. These expenditures were cost prohibitive in low volume environments and cost advantageous in high volume environments. To achieve volume, large builders operated in large markets and performed in-depth market research. Midsize builders lacked the same level of market research resources and operated in markets with smaller customer bases. These builders achieved volume by targeting larger customer segments through flexibility.

Other elements of large builders' processes were harder to mimic, or less important in smaller markets. (e.g. expensive land costs in large metropolitan areas like California made lot frontage and lot utilization important metrics for controlling land cost, semi-custom building made marketing missteps less severe). While midsize builders were unable to mimic the complete production process of large builders, the elements they adopted were essential for their success. Semi-custom building allowed utilization of these processes.

Semi-custom building did result in challenges. Primarily, these challenges revolved around four major concerns: exponential growth in purchasing and estimating responsibilities from uncertainty in products and assemblies, mistakes and errors from inadequate communication, difficulty paying trades correctly, and poorly defined limits to customization. These challenges are outlined in greater depth in Section 4.1.4.

4.1.3 Small Custom Builders

The last subset of experts worked for, or owned companies, building under 40 homes per year. The contractors in this category were truly custom and used few if any production home building processes. They built homes across a much wider range of prices ($250,000 – millions) and lacked a plan portfolio. The builders in this category built very few if any spec homes.

These contractors' processes were substantially different than the other companies. Small builders revolved around an owner/operator, who was heavily involved in all aspects of the preconstruction and construction processes. The owner also consulted with the customer. In a custom environment, this had numerous advantages. Primarily, the customer's contact had knowledge on the effect and price of custom changes, and authority to authorize those changes.

Other aspects of small builders' process increased flexibility. These builders used allowances for almost all finishes. This eliminated the complicated communication process between customers and trades in other subsets. It also gave customer access to the complete array of trades finish options.

Plans were drafted and estimated after the customer provided a reasonable understanding of wants and needs. This provided estimators certainty in the product and specifications they were purchasing. Bidding was handled after plans were complete, or builders waited for trades to submit invoices after the work was completed. This reduced or eliminated the difficulty in paying trades.

Customization in small builders' process was simple enough that most experts didn't recognize, and had little experience dealing, with the difficulty of customization. However, there were other significant disadvantages of these processes. Reliance on one person's expertise made growth difficult. Cost and process controls were limited. The sales process was more cumbersome, as customers visited multiple locations to pick finishes.

4.1.4 Challenges with and Processes for Increased Customization

Section 2.5 highlights an important principle of customization, that uncertainty causes exponential growth in workloads and problems. This exponential growth makes customization processes unmanageable. The solution, according to the theory on mass customization, is modularity. During the first-round interviews, experts noted six areas where uncertainty and exponential growth created unmanageable processes including: communication with the customer, communication with trades, the bidding process, including upgradable materials in base house assemblies, finish option pricing for custom structural options, and exponential finish option growth.

Semicustom builders utilized several processes to manage these challenges. They also theorized on additional processes which would increase flexibility but required changes to software and systems to implement. The following process changes were particularly helpful in increasing preconstruction flexibility: negotiating generic assembly level unit pricing with trades, building an estimating system which understood those assemblies, negotiating finishes into tiers, storing finishes generically in structural options, removing upgradable material from base house assemblies, and automating the structural and finish option pricing at point of sale.

One expert provided a hypothetical example how uncertainty and communication make a simple custom request difficult to handle. He states,

> One of the biggest challenges, is having them clearly communicate what they want. For example, they may want a certain shower configuration, [such as] two shower heads, a rain head, and some body sprays. The builder has to communicate where they go, the functionality they are looking for, and whether it is controlled by one or multiple valves. It is these layers of questions that need to be answered. Typically, you have a sales person… who may not understand the details needed in a custom option. You spend a lot of time trying to communicate, trying to get all the questions answered. It is a back and forth process that really slows things down in order to fully understand exactly what their expectation is.
>
> They see a picture on Houzz® or something they have in their prior house. But they don't understand the specifics enough to communicate that to us. It takes someone with a little more skill and expertise to ask the right questions and to get the right information…It takes more time and energy on one simple thing like a shower configuration, and then you multiply that by 20 or 30 different things that they want.

This example demonstrates many areas where communication presented challenges. Under existing processes customization required a complex communication path. The communication loop traveled from customer, salesperson, estimator, multiple trades, estimator, salesperson, customer. At any point, inaccurate, incomplete, or miscommunication could have caused the process to repeat. The complexity of the path also created high potential for errors.

Other concerns besides communication exist in this example. In multiple areas, people lacked information necessary to perform tasks or make decisions. Under the typical sales process, customers would have selected layout options (i.e. shower) before selecting finishes (i.e. tile, shower trim). Without finish option selections, the estimator could not price this option.

The process could have been adapted, so customers selected finishes prior to the custom option pricing request. However, this presented another challenge. Price was a significant factor in the sales process and finishes dramatically affected cost. Tile showers commonly ranged from $4,000 - $10,000 based on the tile, shower trim, shower door, etc. Without finish option pricing, a customer on a $6,000 budget could have easily selected a $9,000 shower. Customers needed finish option pricing to make informed decisions.

A related problem occurred with builder specified customization. Any structural/layout change a builder offered created uncertainty in finish option pricing. Consider the interior door options on a plan with an optional finished basement. Interior doors ranged from $70-$400. Assuming the plan has 15 doors upstairs, and 20 downstairs, should the contractor assume the $400 interior door option will cost $4,950 (i.e. ($400 - $70) * 15), $11,550 (i.e. ($400 - $70) * 35), or create two options. Among experts, pricing every permutation of option was the most common solution. However, this solution was far from ideal. It created confusion for sales, forced estimators to manage thousands of options on each plan, and dramatically increased workloads.

The experts had partial solutions for these problems. One expert's process dramatically increased communication. He eliminated drafting and purchasing as distinct roles. Instead, he created a project manager position. This position was responsible for drafting in a BIM environment and estimating. The project manager also met with the customer during preconstruction.

The project manager position had several advantages. This position greatly simplified communication between the customer and estimator. It also increased accuracy and accountability.

Other challenges with customization in preconstruction included: clear communication with trades, trade payment procedures, finish option pricing, and BIM setup. One expert demonstrated how a unit price database simplifies these problems. He states,

> Let me make some definitions here. We define a custom builder as someone who can take a drawing off a napkin and design and build it. It's what we would call a design build firm.
>
> [In the design build process] a customer comes off the street and says, 'I'm thinking of this idea for a house and this is what I want.' Then they sit down with a design

> draftsman who will draw it out. After the house is drawn and the customer approves it, they bid all the parts and pieces… [The design build firm] would charge them a percentage to build the house versus an actual sales price margin. That's what I consider custom building.
>
> Everyone else is a semi-custom builder. If you are working off a portfolio of plans, then you are a semi-custom builder. Having said that, the difference is *the databases for [semi-custom builders] are completely detailed.* All the lumber is completely detailed. In some cases, they may stick frame roofs, so they are not buying trusses. [Instead,] they are buying all the pieces and parts for the for the roof system to be built on the site.
>
> We have a scope of work for the electrician that says this is our base level, and he charges us a price per square foot [for] the base level. Everything the customer wants above that base level would [then] be one-line addons.
>
> When you have a completely detailed database with all the items that someone could want, [then] *that database becomes more difficult to maintain. [However,] it becomes very easy and very quick to put a semi-custom house together.* [Emphasis Added]

For semi-custom builders, unit pricing was highly advantageous, because it was highly modular. Unit pricing allowed estimators to respond to custom pricing requests without contracting trades. It also simplified and standardized communication with trades for construction. Under this process, trades expected information to come in very consistent ways (i.e. plans, specifications, and purchase orders).

Unit pricing also simplified builder specified customization. Because bids lack modularity, bidding all options on master plan sets was an extensive process. During the bidding process, trades were forced to bid every permutation of options. Unit pricing simplified purchase negotiations, but increased estimating workload.

After an explanation of mass customization theory, the previous expert used past mass customization experiences to theorize how residual problems in the residential preconstruction process could be overcome. (i.e. estimating workload, finish option pricing, and BIM setup). His process contained several key points: leveraging strategic relationships with trades to negotiate simple unit pricing structures, using software to develop simple estimating processes, using BIM to generate generic key measures, and automating option pricing at point of sale. Many experts had similar conclusions. He states (*solutions italicized*),

> Expert: I used to work for [redacted] in another lifetime and I actually built cabinets. I was a special builder. Even though these were box cabinets that you would buy, the assembly line we built on allowed us to build any kind of cabinet, in any color, in any style; the only limitation that we had was the cabinet couldn't be bigger than what could fit through a standard three-foot door in a house. As long as we could put it in a box and it would fit through the front door, we could build it. It was all componentization [i.e. modular construction]. We had five different styles of hinges we could put in. We had a big clamp where the cabinets were built in. This clamp could build up to eighty inches long, forty-eight inches in height, and fifty inches in depth. We could customize almost anything based on the parts and pieces we could choose from.
>
> Researcher: [Let's take that idea from cabinets and apply it to a house]. Cabinets are pretty simple. You only have ten or fifteen different components. You have your melamine, hinges, drawer glides, fronts, and your panels. You have a limited array of options. Take that idea, and scale it up to a house. Let's say you have a house built out of these assemblies. you have my walls, siding, drywall, and you can stretch and scale that any way you want. But, you only offer that array of assemblies. So, you setup your database to handle those types of assemblies. You can sit down with a customer and draft a plan [using those assemblies] and very quickly have a price. But you also keep the efficiency [redacted cabinet supplier] had. Would such a system be possible?
>
> Expert: I don't think the system's too big at all. I think we've almost gotten to the point we're trying to compartmentalize estimating too much. We want to fit everything into assemblies. The reason we're doing that is we now have pieces of software that can analyze the house drawings and automatically pick out that what assemblies go into it. [Instead, if we use processes from] twenty years ago, [such as using] Excel or a simplified database, I think we can handle this stuff very easily with some of the new software advancements. If we take pieces of the new and pieces of the old, I think it becomes very easy to handle a fully customizable product—and not get bogged down with time constraints or giant databases that we have to [maintain]. *It's all about your relationships with your vendors, how you want them to price certain things, if they will price that for you, and using software to your advantage for the most part.*
>
> Researcher: What do you see missing from a software standpoint in order to make the connection where a customer can walk in and make some drafting changes, and then have them a quote hopefully before they leave, if not, by the end of the day; then, on the back end have all those parts and pieces ready to show up at the job

site in a very quick manner? What processes, software, and systems do you still need to see that happen?

Expert: My [struggle] right now is *having several separate standalone pieces of software that will do all these parts, but they don't talk to one another. If I could automate the talking to one another, it would make it quicker.* I have two specific builders that I'm thinking of that do full customization of their product. If they were to hand me a plan that was ready to estimate, I could have them a cost for the house within two hours with a fully customizable product. Now, that having been said, we don't work on those timelines, and rarely do we have to. I don't know [if that timeline is maintainable] on a daily basis—that is, a customer walks in with a fully customizable house and we price off the cost—I don't know if that would be physically possible, but I do know that it theoretically is.

Researcher: Let's say that BIM based software will kick out an assembly and you can get much more accurate pricing based on an assembly. I'm not sure of the time frame, but you schedule a meeting where the customer sits down with the sales person and the drafter and sketches out their product. That links to an assembly or higher-level estimate, that's more detailed and accurate than square foot house pricing. [The software understands that] I have this many sinks and the sinks cost this much. It also understands that it is a base level sink. After, the customer can walk into a selection center and upgrade, and because the software knows how many sinks are in that home, the price for that option is adjusted based on the number of sinks they are upgrading. You still keep that production mentality where you still have pre-canned options. Customers like the selection center, but you are also allowed to make those custom changes. You can keep that to an assembly level. Once that is done, you get to the finer details such as the lumber pack and the shingles.

Expert: I see it more as, *I want the BIM software to give me the measurements of everything, and the counts.* I want the linear foot of exterior wall, the linear foot of interior wall, the square footage of each room, the counts, doors, and windows, what they are. [I want it to] hold that information. As the selections are entered into there, then those two things are combined to create my estimate. We may be talking about the same way, but that is how I see it.

Researcher: The one thing I see about that is if the customer chooses a three-hundred-dollar faucet and has a [huge added cost] to their home they weren't expecting. [The company needs to have] the ability to price out fit and finish items for the house, so the customer can make selections and know how much the selection's going to add to the house.

Expert: In my mind we would already know what the kitchen faucet cost for the base house. [If] the base house kitchen faucet costs a hundred and fifty dollars then when they are in the selection center and they say, 'we want this gold-plated faucet right here.' *Then the salesperson would be able to say 'this is gold plated faucet*

> *that cost five thousand dollars and your base faucet costs a hundred and fifty dollars, so five thousand minus one hundred and fifty is four thousand eight hundred and fifty dollars.'* So, she could quote right there, 'well that's possible Mr. and Mrs. Smith, but it's going to add four thousand eight hundred fifty dollars to the base price of your house.'
>
> Researcher: [Providing selection to the customer is highly advantageous. It allows [customers] the option to make adjustments at that point. There is a reason why production home builders like a selection center. Having the salesperson armed with sales pricing up front is valuable to a customer. What would need to happen for [selections] to work with a custom plan?
>
> Expert: Once again, we'd still just need the measurements. If we came out of the design meeting and we had the measurements of the house and it was broken down, then there would have to be another system in place at the sales level for selections. [The salesperson would need the ability to easily make selections.] They want to upgrade the master bedroom to carpet level C, all the way to the bottom of the selections. [The salesperson] could pull a drop-down box for the master bedroom flooring and select carpet level C. *The software would know the square footage of the master bedroom and that carpet level C costs this much and the base price was this much. So instantly the salesperson could say, 'that is going to add three thousand dollars to the base price of your house.'* [The customer] could make a decision right then and there.
>
> Expert (cont.): We're talking about completely turning it around. If you were running [redacted software] in a BIM [environment] with [redacted software,] they have it setup right now so that they are making their selection upfront. We're talking about completely changing that around to where they are physically designing what their house looks like and pulling together a price on that. *Then they are making their selections at that point, so they can see how it affects the price of their house as they are making their selections.* [Emphasis Added]

While this expert had experience with much of the proposed process, parts of the process were theoretical. The theoretical parts included automating finish option pricing at point of sale and an integrated BIM software solution. However, other experts had experiences which helped validate these points.

> We have our flooring, tile, and granite in price levels… We have it setup on unit price. The designers are pretty good at applying a unit price. So, they say it has approximately 50 SF of granite in it, and to upgrade a level it is $4 a SF… The designers have a lot in their hands in that respect.

> “We don’t allow the designers to do the more complicated options, ones that involve multiple scopes. We only them to do it when they are very straightforward, and they have the unit price that applies to just that elevation or area.

This example was limited in application to simple phases with one simple key measure. This was primarily due the complexity of measuring and pricing multiple key measures. These limitations could have been overcome through automation. However, even a limited application shows the power of pricing finish options at point of sale. Without the process, this builder would have been forced to price and store hundreds, or thousands of countertop options. This process limited countertop finish options to four or five levels.

The software application had also seen limited application in related industries. The insurance restoration industry uses a BIM style software to price drywall, carpet, and baseboard. The application was limited to a few construction phases, but the principle applies. As one expert states,

> I think there are systems out there that already do that. What is interesting, we have had a few [employees] come through that have worked in the restoration business. [insurance restoration estimating] software is really pretty good at doing that... You can stretch and move a room around, and it will calculate all the necessary quantities for you. I think that it is a great idea. It is a very good idea. The challenge is finding the software that reflects what you are actually doing.

Based on the results of the feedback provided during the first-round interviews, a proposed process was developed to solve the problems described by the industry experts. This proposed process contained the following key elements: maintaining strong relationships with vendors, negotiating unit prices with vendors in easily estimated assemblies, using software advantageously, automatically calculating finish option pricing after layout options were selected, and generic but data rich BIM models.

Estimating process efficiency was essential to the proposed process. The estimating process needed to be simple, repeatable, standardized, and cost effective. Vendor relationships played a key role in building that process. Simplifying the process occasionally required innovative pricing strategies. Negotiating such prices required a high degree of mutual trust in vendor relationships.

As shown, this process contained great promise, and warranted further research. In particular, the complete process needed validation in the expert community, strategies for customization limits needed development, and the effects of unit pricing as well as effectively using BIM in preconstruction warranted further research. These questions are the basis for the second-round interviews.

4.2 Second Round Interviews

Section 2.5 of the literature review showed how customization exponentially increases process complexity. This problem is overcome through modularity. After analyzing the first-round interviews, and developing a process for customization, six areas in the residential preconstruction process were identified which inhibited customization (See Sections 3.2.3 and 4.1). These include: communication with the customer, communication with trades, the bidding process, including upgradable materials in base house assemblies, finish option pricing for custom structural options, and exponential finish option growth.

During the second round six experts were interviewed with experience in residential preconstruction processes and systems. Their expertise primarily focused on purchasing, estimating, and sales pricing processes. One expert had additional experience with drafting and BIM. The second-round interview process had three goals: validating the first-round results, analyzing if the proposed process would alleviate these concerns, and identifying the effects of the proposed process.

The results were positive, and these experts strongly agreed with the challenges identified during the first round. Overall, they agreed the proposed process would alleviate many concerns with customization. However, the process would have significant effects on company structure, cost control strategies, trade relationships, and leanness. For this reason, it is important to understand the limitations of the process. Due to these limitations, the process would not work for all contractors, and in all markets.

The results from this round follow the general interview structure. The interview structure had three sections. First, experts were presented with a case study, to ensure they agreed with the researchers' analysis of customization limitations (Results section 4.2.1). Second, the proposed process was presented (Results section 4.2.2). Last, the effects of the proposed process were studied (Results section 4.2.3 and 4.2.4). An additional section (4.2.5) covers BIM processes in relation to mass customization.

4.2.1 Modularity in Sales Option Pricing

During the first-round of interviews, sales option pricing was identified as a significant challenge with customization. Using current processes, product uncertainty prior to the sale caused exponential option growth. This occurred in a few areas including: structural options changing the quantity and price of finish options, systems unable to aggregate a sales price from multiple options, and custom options creating uncertainty on the finishes that need to be priced.

For the second-round interviews, a simple case study was created to demonstrate this problem. In the case study a builder offers three kitchen layouts, an optional kitchen island, and four other cabinet layout options. In addition, the builder offers five styles of cabinets, and four styles of countertops. Pricing these options presents many challenges. Correctly pricing the finishes requires 72 options (8*5 cabinet finish options, and 8*4 countertop finish options). In addition, the base house estimate included the base grade cabinets and countertops. Thus, every option that influenced the cabinets or countertops must first remove the base grade materials. In this scenario, simple changes (e.g. adding, removing, or adjusting a kitchen layout; adding or removing a cabinet finish; adding or removing a countertop type, etc.) can force changes to dozens of options.

This problem was present to some degree in every expert's company. There was a strong agreement this was a significant challenge. As one expert states,

> The challenge with software and option programs, is the maintenance of the system. [With these systems it is difficult] to add and subtract options, be flexible, and make those changes quickly. Everything has to be very clean throughout the entire database, because whatever goes in, goes out to sales. Unless we are really good at [maintaining the database], we are not very good at a system to do [sales option pricing]. You have to have really good purchasing organization data that goes in so that it is structured in a format that is presented in a sales format.

Another expert shared his first attempt setting up a cabinetry pricing database,

> As far as cabinetry goes, we have the base prices for each house, in each style of kitchen in that house, along with the levels for every house. On top of that, at the bottom of that database cabinet list, we have per box pricing for all the different sizes of cabinets. That was something we started early on. Now it is pretty much useless, because of the size of that database. Trying to find [an item] is completely overwhelming. It is in the neighborhood of 20,000-line items just for the cabinets, and that becomes overwhelming to use. If you are searching for something to add as an item to the estimate, scrolling through 20,000 items takes time.
>
> We could create options for everything [that we] were able to [select], and it would be a onetime thing. Once the option was created, we could use it over and over again. By the same token, creating those options manually, without the use of anything else, would have taken us a year probably to break it all down and get it all setup the way it was supposed to be.

Limitations in software programs that maintained option pricing were primarily responsible for this problem. However, experts had some success in limiting the scope of this problem and making it more manageable. Their strategies included: grouping finishes into tiers and levels, consistency in design, unit pricing and strong trade relationships, creating limits to customization which enabled flexibility in other directions, and allowances.

Every builder simplified their finish option pricing by negotiating into tiers or levels. For example, a builder would offer hundreds or thousands of flooring styles. However, they would group them into a limited number of price points and negotiate a price for the entire group. (i.e. Tier 3 flooring would consist of 100 different styles of carpet ranging from $3.15/sf to $3.50/sf. The builder and flooring supplier would agree that all flooring styles in that tier would sell for $3.40/sf.) By grouping finishes, a builder could limit the rate of exponential growth, while offering more finishes.

Tiers simplified finish option pricing but did not eliminate exponential option growth. Contractors typically had multiple tiers, so exponential growth still occurred. In addition, this strategy only worked when finishes had similar assemblies and prices. Grouping divergent assemblies (tile and carpet) was difficult. In addition, this required blending prices (talked about in greater depth in section 4.2.3) which can make costs uncompetitive when taken to an extreme.

Another strategy for simplifying option conflicts was consistent design. When utilized correctly, consistency in design can break the link between structural and finish option. Enabling modularity in finish option pricing. As one expert states,

> We break things into plan specific options, and what we call global options. For instance, if you design around a 30-inch slide-in range, you can [use] any 30-inch slide-in range… We do have those global options. [For example,] to add a light switch anywhere, is pretty much the same cost. Where you get in trouble, is where you try and add a high amperage outlet, that has a different connector. Then you need to know exactly what the buyer is looking for, or you have to give them 50 different options.

In this example, standardizing appliance sizes allowed this expert to have one set of appliance package options, instead of separate appliance package options for each kitchen layout. This is an excellent example of the power of modularity at work.

Consistent design was also essential to achieve flexibility and reliability in trade pricing and communication. As one expert states, "allowing… a lot of variable design… is what frustrates [trades] from getting unit pricing. They don't want to do a set unit price, if they know there are scenarios that are going to make it more costly, or more time consuming." This idea is explored in greater depth in section 4.2.3.

Among experts who heavily customized, controlling the trade price sheets was essential. These companies had robust estimating departments, which eliminated soliciting trade bids from the customization process. However, maintaining house and option estimates required a consistent and predictable set of key measures. Companies who were successful at customizing developed price sheets for each cost code and would only pay trades for items on those price sheets.

The structure of trade price sheets was also critical. Bidding projects inherently lacked modularity, because any changes required communication between the customer, sales agent, purchasing agent, and trade to correctly price. Due to the extended communication loop, unit pricing was superior in almost all instances. However, the depth of unit pricing was also critical. Unit pricing that was too detailed or tracked too many key measures were difficult to maintain, while unit pricing structures that blended too many unrelated items were uncompetitive. For many cost codes, perfect solutions did not exist.

The difficulties establishing a cabinetry price sheet highlight the importance of modularity in preconstruction. The cabinetry phase was the perfect storm in a customization realm. In this phase, customers have a strong desire to customize both the layout and finishes. Small cabinetry changes can quickly affect hundreds of options. Pricing the cabinetry phase correctly also requires many key measures. Earlier, one builder stated developing a cabinetry price sheet had created an unmanageable 20,000-line item database. He also shared his current attempt at pricing cabinets. He stated,

> What we have done now, is we have assigned linear inch pricing to cabinets. For any particular level and any particular style, we have a linear inch price, understanding that cabinet companies that manufacture them are manufacturing them the same way. The linear inch price for a base cabinet assumes it is a single drawer, with doors underneath…On top of that, we have adders for the different cabinet options. [For example, if the customer wanted] to add 30 inches to the bases of the cabinets, but they want that 30 inches to be a 3-drawer, we then have an adder that lets us change that standard cabinet to a 3-drawer…If they want soft close door hinges and all the other bells and whistles, then there are adders for that. Now, that having been said, this is really in its infancy. I really haven't had a chance to test it. It was our best worst idea at the time. Because the next step is trashing it all, and say we are going to bid every house.

This strategy was advantageous because it only required two key measures to price most cabinet changes. However, it also has disadvantages. Because the key measure is heavily blended, it was inaccurate for large changes. He stated it would be insufficient to price an entire house. In addition, negotiating this pricing strategy was difficult, and heavily dependent on a 10-year relationship with their cabinet supplier.

This same expert also shared another strategy he had seen,

> [Another contractor I know] buys per box and has 4 different color/styles that he can choose from. There is grey, there is white, there is oak, and there is something else. Each color is represented in its own style. You can't get the slate cabinets in the Sheffield style. You can only buy the slate cabinets in [the] particular style it is in. He has a very succinct list of cabinets that you can choose from. [In the estimating program] you select the cabinet color or style you want, and then in the actual purchase order sheet, it changes the description, and finds the correct price for that color and style for that particular cabinet. From that point, you go through the list and pick out what particular cabinets you want. This ends up being fairly simple because [the list is only 216-line items].

In this strategy, finish options were strictly limited. Limiting his finish options also limited the size of his price sheet. This simplified price sheet made layout changes very easy to make. However, this strategy only gave the customer four finish options. While this strategy is an extreme example, limiting customization in some areas occasionally was essential for increased flexibility in other areas.

Developing and negotiating these price sheets and establishing customization limits were important elements of a customization strategy. Price sheets are discussed in greater detail in section 4.2.3. Customization limits are discussed in section 4.2.4.

Many experts used allowances to handle some customization requests during the preconstruction process. This process was especially popular among small builders. Allowances do have some advantages for a company including certainty when estimating costs and increased flexibility. However, allowances can also be problematic. First, allowances typically do not allow a one stop shopping experience that many production homebuilders try to create. Instead customers are required to visit multiple trades to select finishes. Second, allowances that are too high lead to lost sales, while allowances which are two low can frustrate customers with unexpected costs.

4.2.2 Proposed Process for Increased Customization

Using first round interviews, changes to the preconstruction process were identified which could increase the simplicity and modularity of the system. The proposed changes included the following steps (outlined in greater depth in section 3.2.3): define the product generically using unit pricing and assemblies instead of bids and master plan sets; negotiate trade pricing targeting those assemblies; define finish products generically in structural assemblies (e.g. lavatory faucet instead of Delta Core B single handle lavatory faucet); group finishes into tiers; remove from base house estimates all items that can be upgraded with an option and house these items in a separate option; automatically calculate structural and aggregate structural option pricing at point of sale; require customers to finalize structural selections prior to selecting finishes; and automatically calculate the price of finish options based on the structure that is selected.

Reception to the proposed process was positive. The experts generally agreed that the process would work, but not all felt it could be integrated into their current companies. It was apparent from their responses that many parts of this process were already in use by various companies. However, software and other limitations prevented a complete application. Even though the application was piecemeal, the elements companies successfully used substantiated this process. It was anticipated a complete application would greatly ease customization limits.

The ability of the proposed process could be seen by comparing the divergent strategies of these experts. Earlier in this section, one expert shared how severely limiting cabinet finishes allowed one company to accurately price most custom cabinet layouts. In this example, he recognized that cabinets with different finishes are constructed the same way. By taking off cabinets in their generic form, he limited his takeoff list to approximately 200 items, even though his pricing database contained 800 items. This made takeoffs manageable. In addition, changing finishes required one click, and Excel formulas updated the option price.

This strategy lacked other elements of the proposed process. This company did not negotiate cabinet finishes in tiers or levels. Thus, every new stain or door style added 200 items to the pricing database. Considering most cabinet shops offer hundreds of door styles and finishes, this database would quickly become unmanageable without limited finishes.

This company built custom homes, so each cabinetry layout was unique. However, most semicustom builder pre-price and store multiple kitchen layouts and options. Being able to easily store, aggregate, and tweak layout options would be an essential element for most semicustom builders. This estimating program had difficulty storing and aggregating layout options.

Other experts had success with other elements of this process. One expert shared how he structured cabinetry tiers with his supplier.

> We have negotiated so that stain type doesn't matter, or if it is a recessed door, it doesn't matter either. If you go to a raised panel, then that would be an additional cost, and an additional option. It just depends on how your option pricing is structured.

Combining this strategy with the previous strategy would greatly increase cabinetry finish options. One could easily negotiate 4 cabinet finish levels (e.g. flat panel oak, raised panel oak, flat panel cherry, raised panel cherry), and offer 20 or 30 stains. Using this strategy would have increased finish options from 4 door styles to 120 door styles.

Storing, aggregating, and tweaking layout options was a bigger challenge. There were estimating programs that specialized in storing layout options. However, the experts were unaware of a program that combined that functionality with the ability to modularize finish options. Developing a software package that was capable of handling the entire process outlined above was highly recommended.

During the first round of interviews, an expert shared another example of this process. In this example, he had negotiated countertop and flooring into tiers using a square foot unit price. He stored the unit price with markup in his sales software. The designers and sales agents were responsible for calculating the finish option pricing for the plan a customer had selected. This simplified his finish option list. However, the process was not automated, and would not work for complex phases (e.g. cabinets).

Separating commonly upgraded structural options from the base model estimate and aggregating these options was an important element of this process. However, most software system lacked the ability to aggregate structural options. For this reason, there was limited data or experience with this process change. The chief concern was ensuring the model estimate is complete and does not lack a necessary option.

It should be noted, when drafting a master plan set, options are not included in the base model. One expert shared their drafting process. When adding an option, they would move all optional elements to another area in the model. They could duplicate and adjust these elements as necessary to create optional layouts.

The optioning process for drafting demonstrates that removing options from the base model decreased complexity. However, this process has a more direct connection to purchasing. The structure of a BIM estimate hinges on the structure of the BIM model. A functional BIM estimating process required a purchasing process, which could aggregate standard structural options into the base model.

The overall response to the proposed process was positive. However, there were some concerns, which primarily revolved around three points: purchasing centric companies lacked estimating staff necessary to adjust for custom changes, efficient companies required highly detailed and difficult to track key measures, and decreased ability to adjust option margins on individual options. For these three reasons, the proposed process would not work with all contractors, or in all markets.

Among the respondents, there were two preconstruction department structures. Three companies were purchasing centric and had few if any estimating staff. The other three companies were estimating centric and used purchasing to provide information to their estimating staff. The preconstruction process was changed dramatically between these structures. Purchasing centric companies bid very specific plans and options for each community. The bid process formatted trade payments in ways that were difficult to adapt to custom changes. For this reason, it was apparent that the proposed process would only work in estimating centric companies. These strategies are discussed in greater detail in section 4.2.3.

Another concern was the level of unit pricing detail. As one expert states,

> Your list of materials would be enormous… You would have to have a price list from all your trades for the various commodities. You would need to be capable of handling commodity changes. Your lumber [typically] changes every quarter, and you would have to make all those adjustments on a quarterly basis.

This expert worked for a purchasing centric company. However, they required highly detailed estimates from all their trades. They tracked small elements (e.g. rolls of masking tape in the painters estimate) on all their houses. When comparing bids, this detail helped identify errors and cost savings. This detail was also essential for their lean construction initiatives, as they could forecast the cost effectiveness of changing construction techniques.

Maintaining a unit price database appeared overwhelming to one purchasing centric company. However, multiple other companies maintained a database. It appears that much of the discrepancy between these experts was the level of detail they typically tracked. Unit pricing was essential for estimating centric companies who heavily customized. However, the structure of that pricing was also critical. Unit pricing is discussed in greater detail in section 4.2.3.

One expert expressed a minor concern with option margins. To increase option revenue, they adjusted margins based on the popularity of an option. The proposed process decreased the number of options. While the proposed process does allow some variation in option margins, a decrease in the total number of options would decrease the detail with which option margins could be adjusted. While this expert did not feel this was a major concern, he did feel it would take time to get used to.

4.2.3 Trade Relationships and Unit Pricing

The ability of a company to customize successfully was deeply tied to their relationships with their trades and the structure of their price sheets. Strong, long lasting, and ethical trade relationships allowed innovation in communication and payment processes, thereby increasing a contractor's ability to customize. While having accurate and comprehensive price sheets were essential to processing changes efficiently. The importance of these two elements cannot be understated.

Many experts stressed the importance of developing strategic alliances with trades in complex and heavily customized areas of construction. As one expert states,

> You can…allow the buyer to customize the kitchen if you are intimately aligned with a trade partner that can handle it. Our cabinet company right now is also the design company that meets with the buyer, so, they can do it. We establish a margin that the builder is going to make, and they bake it into their cost. If they meet with the buyer, and the buyer wants to do some crazy kitchen that is going to cost $20,000 for the kitchen cabinets…, then if we want a 50% margin, for example, the retail would be $40,000… Because they are designing it themselves, they are providing the cabinets themselves, and it doesn't really impact any other trades other than countertops. When we set it up, we just have a custom option code for cabinets that we setup at $0.50 on the dollar, for a 50% margin. With the $40,000 option, we would pay them $20,000 and make $20,000 in margin.
>
> If you are strategically aligned with a trade that has the capability of doing that and is meeting with the buyer, you can do it. Otherwise it is very problematic.

Every expert had examples of strategic alliances allowing innovative solutions to the complexities of customization. The company in the example above was among the most rigid. They offered very little customization. However, recognizing cabinetry was an important area for customization, and strategically aligning themselves with their cabinet supplier allowed almost unlimited flexibility in this difficult construction phase.

Strategic alignment requires mutual trust and a long-term relationship. In the example above, outsourcing their design studio complicated the cabinetry bidding process. Without securing a long-term agreement that maintained cost competitiveness, major disruptions to their process would occur every time they switched cabinetry suppliers.

The importance of strategic alignment must not be overrated. Among experts, most difficult phases required a high degree of financial openness, and innovative solutions to maintain flexibility. Other examples of strategic alignment are scattered throughout this section.

Trade relationships were also a critical element of the respondents' company structure. There were two definitive preconstruction department structures among the respondents. Some companies were purchasing centric and allocated their overhead towards purchasing staff. Others were estimating centric, with minimal purchasing staff. These structures had dramatically different effects on a company's ability to control costs and customize.

Purchasing centric companies operated in very defined subdivisions. Scattered site building was uncommon. Prior to the community grand opening, a limited number of plans (typically 2-10) were selected or designed for the specific community. A formal community bid process was conducted, in which the trade provided lump sum prices for the base house and each applicable option. Trades were responsible for all estimates, and unit prices or detailed estimates were only required for bid verification and process improvements.

Purchasing centric companies had several advantages. The formal bidding process allowed trades to define their pay structure. This could increase the number of trades willing to bid and removed uncertainty in work scope. Increased certainty could increase trade bid competitiveness.

These companies also had increased options for lean construction and other cost cutting measures. Because bids were tied to specific options, companies could take advantage of plan and option specific efficiencies. The repetitive nature of their construction meant companies could spend more resources value engineering their plans.

Purchasing centric companies were the most rigid. When asked about customization, one expert stated his company could not estimate custom requests because they did not have the estimating staff. They also lacked unit pricing necessary to perform those estimates. Custom requests were typically limited to a few high priority areas. For example, one company had unit pricing to add masonry to the front elevation but limited most other changes. Another company had their electrician, flooring supplier, and cabinet supplier meet with the customer during the design appointment. They allowed limited customization in those phases but limited most other types of customization.

Maintaining simplicity for the bidding process also required limiting builder specified customization. While most estimating centric companies would offer most, or all, plans in every subdivision, purchasing centric companies typically had a very limited selection of plans they offered in each community. Purchasing centric companies would also limit their option list based on the target market for the subdivision.

While purchasing centric companies had strict customization limits, they had advantages when targeting disparate customers groups in different subdivisions. Varying standards and included features between subdivisions was relatively easy. Through this, the same model could be offered at vastly different price points, and target vastly different customers groups in different areas of town. This was more difficult, but possible for estimating centric companies.

Estimating centric companies used processes which allowed more flexibility, and customization. However, these processes also made some forms of cost control difficult to implement. Typically, estimating centric companies had a portfolio of plans they offered in all communities/subdivisions where they operated. Scattered site building was common. These companies had an in-house estimating team, which was responsible for maintaining the estimates for all base houses/options. The purchasing team facilitated this by negotiating unit prices with most trades.

By maintaining a unit price database, estimating centric companies simplified the custom change process. However, these databases had stringent requirements to ensure they were useable. A well-structured database was robust enough to handle most changes without need for further contract with trades, sufficiently detailed to remain cost competitive, and allowed straightforward and simple estimating processes. However, these goals were often conflicting. Understanding tradeoffs between these completing priorities allowed purchasing agents to develop an effective preconstruction process. Innovation through strategic alignment with trades could reduce required tradeoffs. The balance of maintaining these completing priorities was very delicate. It was easily upset by unclear, or pliable customization limits (section 4.2.4).

The requirements of estimating centric companies forced them to control a trade's pay structure. Maintaining that structure was essential to developing an estimating process. As one expert states,

> It is also essential that when you are first negotiating you make clear the necessity of bidding according to your system and how bidding to a system can increase costs.
>
> This is where personal meetings with vendors makes a difference. You bring them in, you sit them down, and say, 'listen, here is our pay structure. We pay on time, every time. Here is how we like things priced out. We are not so much concerned with how much you charge us. (You don't say it like that, there are other better ways to say it.) We are more interested that you fall within how our system works. We want you to use our system. Because that is more valuable to us.' More often than not, they are willing to fall within that system.

For contractors to control the pay structure, three elements were essential: defining clear expectations at the start of negotiations, long term trade relationships, and a willingness to accept higher prices to maintain the pay structure. These companies would not work with trades who refused to price work according to their pay structure.

An example in section 4.2.1 shared how long-term relationships can help customization in difficult construction phases. In the example, an expert was able to negotiate linear inch pricing for cabinetry. This greatly increased their ability to customize; however, it was difficult to negotiate. This expert doubted a new contractor could negotiate this price structure.

Another expert shared how their plumber was initially hesitant to separate fixtures from their bid. Detailed cost sharing can harm trades through unethical business practices. However, fixture pricing is essential for modularity in the plumbing phase (demonstrated later this section). By working with this trade for three years, this expert gained trust, and was able to separate fixtures from the bid.

In many instances, controlling the pay structure increased costs. These builders routinely accepted minor instances of increased costs. As one expert states,

> I live by the motto that knowing my price is far more important than trying to get the best price. The more knowledge I have on what things cost me, and what my house is going to cost me, is far more important than the minutiae of finding who is going to give me the exact best price on plumbing supplies.

This contrasted with purchasing centric companies. While these companies also found trades working within their process was essential and were willing to pay more for good trades. However, these companies also understood the power of small cost savings. One expert stated $50 could be a material or significant cost in the home.

It is important to clarify how $50 is a significant amount in a home. Using that statement, it is easy to assume this expert would switch framers for $50. This is not true, as this expert also stressed strategic alliances with trades. Their framing company had worked with them for almost a decade, and jointly developed/learned their specific framing process. They had very specific requirements on how corners, showers, wall intersections, etc. were framed. They were willing to pay hundreds, or even thousands of dollars more for a trade who was willing reduce material costs, and warranty issues through continual process improvement.

While this expert was willing to pay more for trades who followed his process, he was also actively looking for process improvements which would reduce costs. The purchasing department had quarterly goals to come up with 10 process improvements to reduce direct costs. Typically, those process improvements averaged $50-$100. Across the 300 homes his division constructed annually, finding 40 process improvements for each home, with a savings of $50 each, would generate $600,000 profit. For this reason, their trades provided very detailed cost estimates. They tracked items as insignificant as rolls of masking tape on the painter's bid.

Estimating centric companies were forced to blend costs to maintain process simplicity. Blended costs, in most instances, were unacceptable for many purchasing centric companies due to the power of small cost savings.

Builders controlling the price sheet structure could also make trades nervous. Trades wanted to ensure they were paid fairly. Builders who were unable to demonstrate fair estimating practices or certainty in trade scopes struggled during purchase negotiations.

When negotiating with new trades, builders occasionally needed to demonstrate their estimating practices. They also had to demonstrate they included a minor amount of fluff, to ensure trades were covered in all circumstances. As one expert states,

> I have been working with a roofing guy…and he wanted to bid all the roofs out. I said, 'I don't want you to bid all the roofs out. I want to be able to put them in Planswift, and tell you how many squares we need, and send it out to you.'
>
> He says, 'well, if you are wrong, are we going to write a VPO [variance purchase order]?' I said, 'let's do this exercise. Let's take three houses; I will take them off, you take them off, and we will see how close we are.' In all those examples, we were both within $50. I said, 'we will pay you the amount of the purchase order every time. Sometimes it is going to be $50 in my favor, and sometimes it is going to be $50 in your favor, but we are just going to accept it. If it is ever over $200 we

> will revise it and write a VPO for it.' He agreed to it, and it has worked fine ever since. Out of 75 jobs that he has done so far, there was one that came back for revision.
>
> When I think about purchasing as it relates to estimating, purchasing is the salesmen aspect of [estimating] and trying to get prices from your trades. I want to look at it from that point, because me losing $50 on the house is so much less important than me knowing how much the house is going to cost.

Builders also had to demonstrate a consistent scope. An inconsistent scope made trades nervous and could also make the estimating database unmanageably large. As one expert states,

> I think that it boils down to consistent design. If you are allowing…a lot of variable design, that is what frustrates people from getting unit pricing. They don't want to do a set unit price if they know there are scenarios that are going to make it more costly or more time consuming.
>
> Our design head is an artist, who really struggles with consistency. Yet, in his own mind he thinks that he is consistent because [he] always uses 4 inch trim on everything. But, the way [he] configures it is different. There are always exceptions and it is always changing. We are kind of our own worst enemy because design can change things without purchasing approval. There really needs to be a clear understanding between those two departments and decision makers.
>
> Trim carpentry! I hate trim carpentry… because we have too many trim details; everything from crown molding to shadow boxes, to mud benches, to different stair details, and shelving. Yea, we got our shelving down to a unit price, but design changes our shelving all the time. So, you are constantly counting and measuring shelving.

Consistent design is deeply interrelated with customization limits, which are discussed further in section 4.2.4.

Experts also stressed the importance of structuring their database in a simple and logical manner. Each construction phase had unique challenges to managing pay structure. There was a delicate balance between ensuring prices were competitive, and that estimates were easy to perform. In many instances, trades would default to pay structures that were unmanageable for estimating staff. Over time, the experts had developed pay structures which were simple to estimate and were acceptably cost competitive.

Experience in a broad range of markets aided development of simple and logical estimating databases. In different regions trades price work using different pay structures. Having experience in many different price structures enabled purchasing agents find the easiest method to estimate work.

One expert shared how a simple phase like wire shelving can be unmanageable. Wire shelving comes in numerous lengths and has many accessory parts. Tracking all the different lengths of shelving, clips, etc. in a highly customizable phase was unmanageable. It was much easier to estimate a linear foot price for shelving. However, a linear foot price was more difficult to negotiate.

A similar problem occurs in flooring. Because flooring is highly competitive, it is common in the industry to increase margins through accessory products (e.g. seam kits, flooring transitions, bull noses, etc.). In addition, waste factors, especially with carpet, can be highly variable. Many experts had negotiated an all-inclusive square foot price. However, this practice runs against industry standard, and can be difficult to negotiate.

It was essential for contractors to maintain control of their pricing database. An experience from the researcher may help demonstrate this. When the plumbing phase was originally negotiated, the plumber defaulted to a bid for the house based on the number of bathrooms. This bid included base level sinks, tubs, toilets, and fixtures. The purchase order (P.O.) listed the plumbing bid, and each included fixture as a note. However, the problem came when these fixtures were upgraded. When the fixture was upgraded, the base fixture needed to be deducted from the bid, so only the upgrade price was paid. However, it was also common to add a fixture (dual sinks in master, or a basement bathroom). In these instances, the fixture needed to be added, but it wasn't always clear if the base fixture needed to be deducted. When the typical P.O. was complete, it was

Table 4-1: Original Plumbing P.O.

Item	Unit Price	Qty	Unit	Subtotal
Willow base house bid	$ 8,173.00	1	Bid	$ 8,173.00
Unfinished Basement Bath	$ 825.00	1	Bid	$ 825.00
Finished Basement Bath	$ 675.00	1	Bid	$ 675.00
Dual Vanity in Master Bath	$ 500.00	1	EA	$ 500.00
Elkay Double Bowl Drop In Sink (Inc. in Bid)	$ -	1	Note	$ -
Elkay Double Bowl Drop In Sink	$ 160.00	-1	EA	$ (160.00)
Elkay Double Bowl Undermount Sink	$ 215.00	1	EA	$ 215.00
Delta 440 Chrome Faucet (Inc. in Bid)	$ -	1	Note	$ -
Delta 440 Chrome Faucet	$ 110.00	-1	EA	$ (110.00)
Delta 440 Satin Faucet	$ 140.00	1	EA	$ 140.00
Chrome Towel Ring (Inc. in Bid)	$ -	3	Note	$ -
Chrome Towel Ring	$ 9.00	-3	EA	$ (27.00)
Satin Towel Ring	$ 12.00	4	EA	$ 48.00
Chrome Towel Bar (Inc. in Bid)	$ -	2	Note	$ -
Chrome Towel Bar	$ 21.00	-2	EA	$ (42.00)
Satin Towel Bar	$ 25.00	3	EA	$ 75.00
Chrome Paper Holder (Inc. in Bid)	$ -	3	Note	$ -
Chrome Paper Holder	$ 13.00	-3	EA	$ (39.00)
Satin Paper Holder	$ 15.00	4	EA	$ 60.00
Chrome Shower Rod (Inc. in Bid)	$ -	3	Note	$ -
Chrome Shower Rod	$ 30.00	-3	EA	$ (90.00)
Satin Shower Rod	$ 40.00	3	EA	$ 120.00
Delta Core B SH Lav Faucet Chrome (Inc. in Bid)	$ -	3	Note	$ -
Delta Core B SH Lav Faucet Chrome	$ 80.00	-3	EA	$ (240.00)
Delta Lahara DH Lav Faucet Satin	$ 140.00	5	EA	$ 700.00
American Standard Oval Drop-In Sink (Inc. in Bid)	$ -	3	Note	$ -
American Standard Oval Drop-In Sink	$ 60.00	-3	EA	$ (180.00)
American Standard Oval Undermount Sink	$ 65.00	5	EA	$ 325.00
Mansfield Round Front Toilet (Inc. in Bid)	$ -	3	Note	$ -
Mansfield Round Front Toilet	$ 140.00	1	EA	$ 140.00
32"x60" Fiberglass Bathbay (Inc. in Bid)	$ -	2	Note	$ -
32"x60" Fiberglass Bathbay	$ 490.00	-1	EA	$ (490.00)
3x5 Fiberglass Shower	$ 510.00	1	EA	$ 510.00
3x4 Fiberglass Shower	$ 450.00	1	EA	$ 450.00
Delta Core B SH T/S Faucet Chrome (Inc. in Bid)	$ -	2	Note	$ -
Delta Core B SH T/S Faucet Chrome	$ 50.00	-2	EA	$ (100.00)
Delta Lahara T/S Faucet Satin	$ 150.00	1	EA	$ 150.00
Delta Lahara Shower Faucet Satin	$ 130.00	1	EA	$ 130.00
Chrome Waste and Overflow (Inc. in Bid)	$ -	2	Note	$ -
Chrome Waste and Overflow	$ 30.00	-2	EA	$ (60.00)
Satin Waste and Overflow	$ 35.00	1	EA	$ 35.00
Satin Shower Drain	$ 45.00	2	EA	$ 90.00
50 Gallon Electric Water Heater (Inc. in Bid)	$ -	1	Note	$ -
Total				**$11,823.00**

two to three pages of adding and deducting fixtures from a base bid, and typically contained errors. Table 4-1 shows a simplified example of this P.O. format.

Simplifying the plumbing phase involved two steps. Unit pricing was provided for all waste and water line terminations. This eliminated bidding new plans and provided pricing for all rough-ins. The cost of all fixtures was removed from the rough-ins and itemized. This increased the modularity of finishes. The changes to the P.O. structure greatly reduced errors, clarified what was

Table 4-2: Revised Plumbing P.O.

Item	Unit Price	Qty	Unit	Subtotal
Kitchen Sink Waste	$ 275.00	1	EA	$ 275.00
Kitchen Sink Water	$ 225.00	1	EA	$ 225.00
Elkay Double Bowl Undermount Kitchen Sink	$ 215.00	1	EA	$ 215.00
Delta 440 Satin Faucet	$ 140.00	1	EA	$ 140.00
Satin Towel Ring	$ 12.00	4	EA	$ 48.00
Satin Towel Bar	$ 25.00	3	EA	$ 75.00
Satin Paper Holder	$ 15.00	4	EA	$ 60.00
Satin Shower Rod	$ 40.00	3	EA	$ 120.00
Accessory Installation	$ 175.00	1	EA	$ 175.00
Lav Waste	$ 275.00	5	EA	$ 1,375.00
Lav Water	$ 225.00	5	EA	$ 1,125.00
Delta Lahara DH Lav Faucet Satin	$ 140.00	5	EA	$ 700.00
American Standard Oval Undermount Sink	$ 65.00	5	EA	$ 325.00
Toilet Waste	$ 275.00	4	EA	$ 1,100.00
Toilet Water	$ 225.00	4	EA	$ 900.00
Mansfield Round Front Toilet	$ 140.00	4	EA	$ 560.00
Shower Waste	$ 275.00	3	EA	$ 825.00
Shower Water	$ 225.00	3	EA	$ 675.00
32"x60" Fiberglass Bathbay	$ 490.00	1	EA	$ 490.00
3x5 Fiberglass Shower	$ 510.00	1	EA	$ 510.00
3x4 Fiberglass Shower	$ 450.00	1	EA	$ 450.00
Delta Lahara T/S Faucet Satin	$ 150.00	1	EA	$ 150.00
Delta Lahara Shower Faucet Satin	$ 130.00	1	EA	$ 130.00
Satin Waste and Overflow	$ 35.00	1	EA	$ 35.00
Satin Shower Drain	$ 45.00	2	EA	$ 90.00
50 Gallon Electric Water Heater	$ 550.00	1	EA	$ 550.00
Water Heater Install	$ 500.00	1	EA	$ 500.00
Total				**$ 11,823.00**

being ordered, and made custom changes easier to handle. These changes are shown in Table 4-2, which shows a simplified example of this P.O. format.

The original bid system may seem laughably complex. However, this is a natural, if somewhat contorted offshoot of a trade's normal bid process. When asked for a bid, they will typically provide a lump sum for the work, and little additional information. Trades can be hesitant to share the detail in the second scenario, for fear of unethical purchasing practices.

Another expert shared an alternate strategy for pricing plumbing fixtures. In his strategy, he maintained a base bid that included all fixtures. However, he ensured any option that added a fixture included that fixture. His fixture upgrades were the difference between the base grade and upgraded fixture. This strategy further simplifies the P.O. but required very clear instructions when negotiating to ensure the upgrades are priced correctly. Items which are upgraded, but not visible on P.O. (e.g. shower drains or waste and overflow) need clear instructions so the trade is paid correctly when they are upgraded. In addition, this strategy blends some items cost. This provides less visibility and cost controls on fixtures but increases cost controls on rough-ins. Table 4-3 shows a simplified example of this P.O. format.

Table 4-3: Alternate Plumbing P.O.

Item	**Unit Price**	**Qty**	**Unit**	**Subtotal**
Turnkey Standard 2.5 Bath Two Story (Master Down)	$ 7,700.00	1	Bid	$ 7,700.00
Master Bath Shower Only Option - 5'x3'	$ 50.00	1	EA	$ 50.00
Add Second Sink to Master Bath	$ 640.00	1	EA	$ 640.00
3rd Bath Option	$ 2,350.00	1	Bid	$ 2,350.00
Add Level 2 Lavatory Faucet Upgrade - Lahara Satin	$ 60.00	5	EA	$ 300.00
Add Level 2 Master Shower Faucet Upgrade - Lahara Satin	$ 100.00	2	EA	$ 200.00
Add Level 2 Tub/Shower Tim Upgrade - Lahara Satin	$ 105.00	1	EA	$ 105.00
(Accessories in Another Trades Scope)	$ 478.00	1	EA	$ 478.00
Total				**$ 11,823.00**

4.2.4 Customization Limits

Establishing clear limits to customization is essential for mass customization. These limits enable process development, which increase efficiency. However, successful mass customization strategies also mask process limitations from the customer. An expert in the first-round interviews shared an example of a mass customization strategy he had seen. This example demonstrates the importance of customization limits in mass customization. (See also Section 4.1.4)

> I used to work for [redacted] in another lifetime and I actually built cabinets. I was a special builder. Even though these were box cabinets that you would buy, the assembly line we built on allowed us to build any kind of cabinet, in any color, in any style; the only limitation that we had was the cabinet couldn't be bigger than what could fit through a standard three-foot door in a house. As long as we could put it in a box and it would fit through the front door, we could build it. It was all componentization [i.e. modular construction]. We had five different styles of hinges we could put in. We had a big clamp where the cabinets were built in. This clamp could build up to eighty inches long, forty-eight inches in height, and fifty inches in depth. We could customize almost anything based on the parts and pieces we could choose from.

At first glance, this process appeared to have few limits. Customer's had hundreds of cabinet door styles and stains to choose from. They could build very large, or small cabinets, in a wide variety of configurations. However, this process had important bounds. A detailed review of their website showed some limitations. All cabinets used a framed construction method. This company did not construct frameless, or euro style cabinets. They also stocked 16 wood species, and a dizzying, but specific list of finishes. Doors were constructed in five shapes (arched, square, slab, recessed panel, and raised panel). There was specific inside, outside, and panel door profiles the customer could select.

The combination of these specific options left customers with a dizzying array of choices. However, each specific manufacturing process had very defined and manageable limits. For example, a customer request for a specific hinge brand would have been rejected. Such a request would have been unmanageable due to significant process changes (e.g. a new hinge boring machine, a new supplier, time spent purchasing hinges, delays in production while hinges were sourced, etc.).

Defining such limits in construction was difficult. One expert stated, “the second you say custom, in people's minds, they think that anything goes.” However, there were critical limits in preconstruction and construction processes which needed to be maintained.

Customization boundaries varied between companies, and regions of the country. For example, one company allowed many cabinet changes, but refused to move appliances. Moving the range’s gas line required re-permitting the plan set. For this builder, this delay and expense were unacceptable.

Experts cited many other challenges with customization. These included, estimating process changes, onboarding new trades, invalidating trade payment structures/price sheets, structural limitations, municipality requirements, covenants and HOA requirements, and warranty issues. Each of these limitations could cause significant process changes, and experts recognized not all forms of customization were profitable, or beneficial.

Communicating customization limits was a significant challenge. Semi-custom construction companies gained a reputation for making changes. Without clear customization guidelines, it was difficult to reject requests. Such decisions felt arbitrary and reflected poorly. For this reason, many companies performed more customization than their purchasing and estimating managers felt was advisable.

Establishing customization limits was also a challenge. Most experts cited specific examples where they would not or could not customize (e.g. limiting all exterior light changes, due to HOA requirements). However, specific customization limits were difficult to develop, difficult to maintain, and did not limit all undesirable customization. In a highly custom environment these lists were unmanageably long.

One expert had an alternate strategy for customization limits. Instead of limiting specific problems with customization, he limited customization based on principles (e.g. only use assemblies they are familiar with and willing to warranty). The sales team had a card outlining these principles and judged whether a custom request was a good fit for the company. This strategy greatly simplified customization limits and was much easier to explain to the customer and sales team.

Unclear process limitations, and poor communication between departments also made builder specified customization a concern. As one expert states,

> I think that it boils down to consistent design. If you are allowing…a lot of variable design, that is what frustrates people from getting unit pricing. They don't want to do a set unit price if they know there are scenarios that are going to make it more costly or more time consuming.
>
> Our design head is an artist, who really struggles with consistency. Yet, in his own mind he thinks that he is consistent because [he] always uses 4-inch trim on everything. But, the way [he] configures it is different. There are always exceptions and it is always changing. We are kind of our own worst enemy because design can change things without purchasing approval. There really needs to be a clear understanding between those two departments and decision makers.
>
> Trim carpentry! I hate trim carpentry… because we have too many trim details; everything from crown molding to shadow boxes, to mud benches, to different stair details, and shelving. Yea, we got our shelving down to a unit price, but design changes our shelving all the time. So, you are constantly counting and measuring shelving.

This expert struggled to maintain a trim estimating process, due to unclear trim specifications. Their trim pay scale was constantly invalidated due to new trim configurations. Their trades were nervous to provide unit pricing for trim, due to unclear specifications.

Sales agent buy in was another common internal customization concern. One company primarily used external sales agents (i.e. realtors). Their purchasing manager stated it was difficult to develop a process, due to the large number of sales agents they would have to train. In addition, external sales agents had little incentive to follow their process.

4.2.5 BIM in Preconstruction

In section 2.5, two strategies for mass customization were identified: modularization (i.e. interchangeable component customization) and product family architecture (i.e. stretchable and scalable customization). One important element of stretch and scale customization was a parametric modeling system (BIM system). This modeling system automated many aspects of the customization process.

Finding experts with direct experience in BIM modeling and BIM estimating proved difficult. The experience among experts who were interviewed was primarily secondhand. Because few experts had direct experience with a BIM implementation, it was difficult to draw strong conclusions. In addition, while mass customization theory states BIM could greatly simplify customization, a general lack of BIM expertise in residential construction serves as a barrier to any effectively using BIM process.

BIM estimating systems needed key measures which were highly detailed, universal, and generic. As one expert in the first-round of interviews stated, “I want the BIM software to give me the measurements of everything, and the counts.” Problems with BIM software came from two areas: missing key measures and non-universal or specific key measures.

While BIM systems contained most key measures, it was common for them to lack some important key measures. For example, one common software was unable to measure roof valley length. Because this key measure is essential for valley flashing, Ice and Water Shield, and sheathing takeoffs, two major construction phases are difficult to estimate without it.

All systems contained some workarounds. For example, these elements can be directly modeled and measured. However, such measurements can be missed when a new plan is modeled, or drafters can fail to delete old measurements. For this reason, such practices are error prone and problematic.

Key measures which were too specific also caused concern. This commonly occurred when finish specifications (e.g. 2868 L 6 panel door vs 2868 L interior door) were drafted into the model. This created a problem, because it fragmented how changes were implemented. In this system, changes to building codes, products, assemblies, suppliers, and trades were not made in one isolated location, but caused drafting changes to dozens of plans.

Another problem was the time necessary to draft a BIM style plan. One expert discussed how BIM increased drafting time. They stated,

> We do everything with smart objects [i.e. BIM], and we are really meticulous with our drafting. We make sure everything is drawn right: all the baseboard is drawn in, all of the soffit boxes are drawn in, and all of the area spaces are drawn in. It takes a lot of time to put together a new plan or take an existing plan and move it to a new community. It is really time consuming… It used to take me 3 weeks to do a plan from blank screen to totally done. Now if I am lucky, it is an 8-week process, and usually closer to 9-10 weeks; and I am a pretty fast drafter. It is much more labor intensive on the front end getting the drafting done. Because there is so much information that comes out of the drafting, we have decided that it is worth the time investment to do that, and to front load everything.

It was unclear why BIM increased drafting time. This particular contractor panelized wall framing, and the additional framing details needed for panelization could have increased drafting time. However, other areas of their plans appeared far more detailed than normal. Additional research was needed to see if this limitation could be overcome.

A hybrid BIM strategy could also reduce drafting time. Such a system would use BIM only for key measures that were easy to obtain. All other key measures would come from a traditional estimate. This strategy also needs additional research.

5 CONCLUSIONS

5.1 Overview of Research

The residential construction industry typically requires a high degree of customization. Customers have shown a strong preference for homes which are unique and individually tailored. However, this presents a challenge. Production process theory shows customization is inversely related to efficiency, productivity, volume, and reduced cost (Section 2.2.1).

The review of literature showed that the inverse relationship between customization and cost reduction could be broken in limited situations through two processes (i.e. modular design and product family architecture) collectively termed mass customization (Section 2.5). Modular design creates interchangeable subassemblies, by standardizing size and connection requirements. This allows limited customization in highly desirable areas. Product family architecture creates a generic product family, which can be stretched and scaled to meet size requirements. These processes were significant because of extensive application in the residential construction industry. For example, light fixtures were highly modular, because they attach to a 4-inch electrical box, and 110 V wire, while wood platform framing uses product family architecture. The prevalence of these processes implied construction customization limits came from the preconstruction process, and not the construction process.

Among large and midsized builders, many preconstruction processes hindered customization including: the communication loop required for custom changes, communicating changes to trades, the bidding process, including upgradable materials in base house assemblies, finish option pricing for custom structural options, and exponential finish option growth. These processes caused most builders to substantially reduce customization as they grew. This research tested whether mass customization principles could increase flexibility in the residential preconstruction process.

5.2 Objectives and Results

The introduction identifies the following challenge in the residential construction industry: the current preconstruction processes used by residential contractors make it difficult to meet the customer's demand for customizability. Four objectives were identified to mitigate this problem: determine if modularity could increase the flexibility of residential preconstruction processes, demonstrate how to price structural and finish options independently, identify how customization and mass customization affects sourcing strategies, and demonstrate how to articulate customization limits.

It should be noted that when this proposed research topic was initially being explored, a fifth objective was proposed: using BIM to enable mass customization in the residential preconstruction process. The literature review shows parametric modeling (i.e. BIM) is an essential element of one branch of mass customization. Therefore, BIM is theoretically an essential element of this process. However, this objective was not studied in depth for two reasons: additional groundwork was needed in the purchasing and estimating processes before BIM could be more effectively integrated within the overall process; also, residential contractors have been slow to adopt BIM processes (perhaps a direct function of the first reason), making expertise in this area difficult to find. Limited results on BIM in residential preconstruction were collected and summarized in section 4.2.5. Additional research is needed in this area.

The research objectives were tested using a qualitative research methodology. Two rounds of interviews were conducted with industry professionals using the Delphi Method. In addition, a process for increasing modularity in the preconstruction process was developed (Sections 3.2.3, 4.1.4, and 4.2.2).

The research results were encouraging. A proposed process was developed to implement mass customization into the residential preconstruction process. The final proposed process contained eight changes to the residential preconstruction process (outlined in greater depth in section 3.2.3):

- Define the product generically using unit pricing and assemblies instead of bids and master plan sets
- Negotiate trade pricing targeting those assemblies
- Define finish products generically in structural assemblies (e.g. lavatory faucet instead of Delta Core B single handle lavatory faucet)
- Group finishes into tiers
- Remove from base house estimates all items that can be upgraded with an option and house these items in a separate option
- Automatically calculate structural and aggregate structural option pricing at point of sale
- Require customers to finalize structural selections prior to selecting finishes
- Automatically calculate the price of finish options based on the structure that is selected

Most experts felt the proposed process would increase the flexibility of the preconstruction process. However, there were important limitations to the process. These limitations have significant effects on company structure, cost control strategies, trade relationships and leanness. Residential contractors need to understand these implications before implementation of a mass customization strategy.

Determining if modularity could increase flexibility in the residential preconstruction process was the first objective of this research. There are many areas in the preconstruction process that lack modularity. These include the following: pricing custom requests required a complex communication loop, which was error prone; custom requests could require significant and burdensome communication with trades; the bidding process resulted in inflexible pay structures; custom structural options lacked finish option pricing; and option lists grew to unmanageable sizes due to option conflicts and software limitations. These areas presented significant challenges to customization in the residential preconstruction process.

It appears that these challenges could be overcome through modularity. For complex customization requests, a meeting between estimators, drafters, and customers could greatly aid communication (Section 4.1.4). Many semicustom builders negotiated unit pricing instead of bid pricing (Section 4.2.3). Automating finish option pricing at point of sale could create finish option price lists for custom structural options and eliminate exponential option growth (Sections 3.2.3 and 4.2.2).

Finding a method to price structural and finish options independently was the second objective of this research. It was determined that automating finish option pricing at point of sale would break the link between structural and finish options. This link causes exponential finish option growth. Many builders identified exponential finish option growth, and "option overload" (Bousquin, 2015b) as a significant challenge to customization in residential preconstruction. Automatic finish option pricing is essential to avoiding this problem. Master plan sets commonly contain thousands of options due to the inherent relationship between structural and finish options. These option lists are cumbersome to maintain. In addition, simple structural or specification changes can force changes to dozens of options on every plan. Automating the link creates a highly modular option pricing strategy, which in turn enables changes to be performed in one isolated location. In addition, this strategy allows finish option pricing on custom plans. (Methods for automating finish option pricing are identified in sections 3.2.3, 4.1.4, 4.2.1, and 4.2.2.)

Identifying the effects of the proposed process was the third objective of this research. The proposed process has significant effects on sourcing strategies. When negotiating unit pricing in a highly custom environment, pay scales need to be simple to estimate and cost competitive. In many instances these were competing goals. Many semicustom builders routinely accept moderately higher prices and blended pay structures to simplify estimation processes. These simplified pay scales also reduce avenues for lean construction cost reductions. In highly competitive and efficient markets, these cost increases may be unacceptable. In addition, negotiating price structures for some complex construction phases requires strong strategic trade relationships. This enables innovative pricing strategies that greatly increased flexibility (Section 4.2.3).

Articulating customization limits was the final objective of this research. These limits are difficult to articulate. Most experts recognized a few difficult customization requests were responsible for much of the increased workload. Eliminating these requests would be highly advantageous. However, it was difficult to communicate and train sales agents on these limits.

The best strategy for articulating customization limits is establishing clear principles for customization. For example, contractors could reject customization requests that require onboarding a new trade, involve unfamiliar products and assemblies, or present warranty issues. Training sales agents on customization principles is far easier than identifying every unacceptable product or process. In addition, clearly communicating these principles helps customers understand why rejecting their customization request is not arbitrary.

Even with the best communication, the preconstruction department will receive some undesirable customization requests. For this reason, purchasing and estimating agents need authority to reject problematic customization requests. (Customization limits are further discussed in Section 4.2.4.)

Parametric modeling (i.e. BIM) is an essential element of stretch and scale customization. These systems automate many aspects of the customization process. However, results on using BIM to enable mass customization were limited. Most experts had limited experience with BIM systems, and finding experts with experience was difficult. For this reason, BIM results were unfortunately limited.

BIM systems need the ability to track a broad range of key measures in a generic way. In addition, it appeared BIM systems require a significantly more intense drafting process. Problems with BIM implementations stemmed from three areas: key measures were too detailed and required significant rework when products or processes changed, important key measures were missing or difficult to track, and BIM implementations were labor intensive (Section 4.2.5).

In summary, the experts who were interviewed generally felt that the proposed process would greatly simplify customization in residential preconstruction. The benefits of this process include: reduced cost of semicustom and custom homes, increased choice for customers, and increased ability to target customers' unique preference for individually tailored products.

5.3 Research Conclusions

Section 3.2.3 outlines a proposed process for implementing mass customization in the residential preconstruction process. Most of the research participants felt that this process would increase flexibility. However, this process would also have potential negative effects on company structure and cost controls. For this reason, the process is not for all contractors, or all markets.

Implementing this mass customization process would be most effective for midsize contractors operating in small markets. In these areas, the volume of homes required by contractors to maintain production homebuilding processes necessitates targeting a broad swath of customers. For this reason, these contractors need much more flexibility in the preconstruction and construction processes. We recommend that contractors in these markets adopt the eight-point process outlined in section 5.2.

Two points in the eight-point process required software automation. However, this automation is not readily available. We recommend preconstruction software vendors develop applications which will handle the automated structural and finish option pricing at point of sale, as outlined in section 3.2.3.

5.4 Recommendations for Further Research

Increasing flexibility in the residential preconstruction process through mass customization proved a fruitful avenue of research. Additional research and process development is needed to implement these findings and further increase preconstruction process flexibility.

A process was developed for implementing mass customization within residential preconstruction. This process was presented to industry experts for feedback and direction. However, it has not been implemented or tested in a construction environment and needs further development and testing.

It was established that most semicustom builders used unit pricing to increase process flexibility. In a highly custom environment, unit pricing was superior for almost all cost codes. However, there were multiple unit pricing strategies for each cost code. These strategies affected cost competitiveness and ease of use. Best pricing structures for each cost code need identification. In addition, unit pricing was difficult to establish for several cost codes. Additional research is needed to develop flexible and efficient sourcing strategies for these areas.

In many BIM systems, some essential key measures were not intuitively tracked. For example, many systems failed to track roof valley length. Maintaining cost competitive pricing structures requires BIM systems to track a broader range of key measures. Additional research is needed to identify a comprehensive list of necessary key measures. Development of BIM systems which track that list is essential.

It was apparent that current software applications create many inherent customization limitations in the residential preconstruction process. Overcoming these limitations is outside the direct control of residential contractors. The process developed in this research and outlined in sections 3.2.3 and 4.2.2 contained many recommendations for software improvements. It is highly recommended those improvements are developed and tested.

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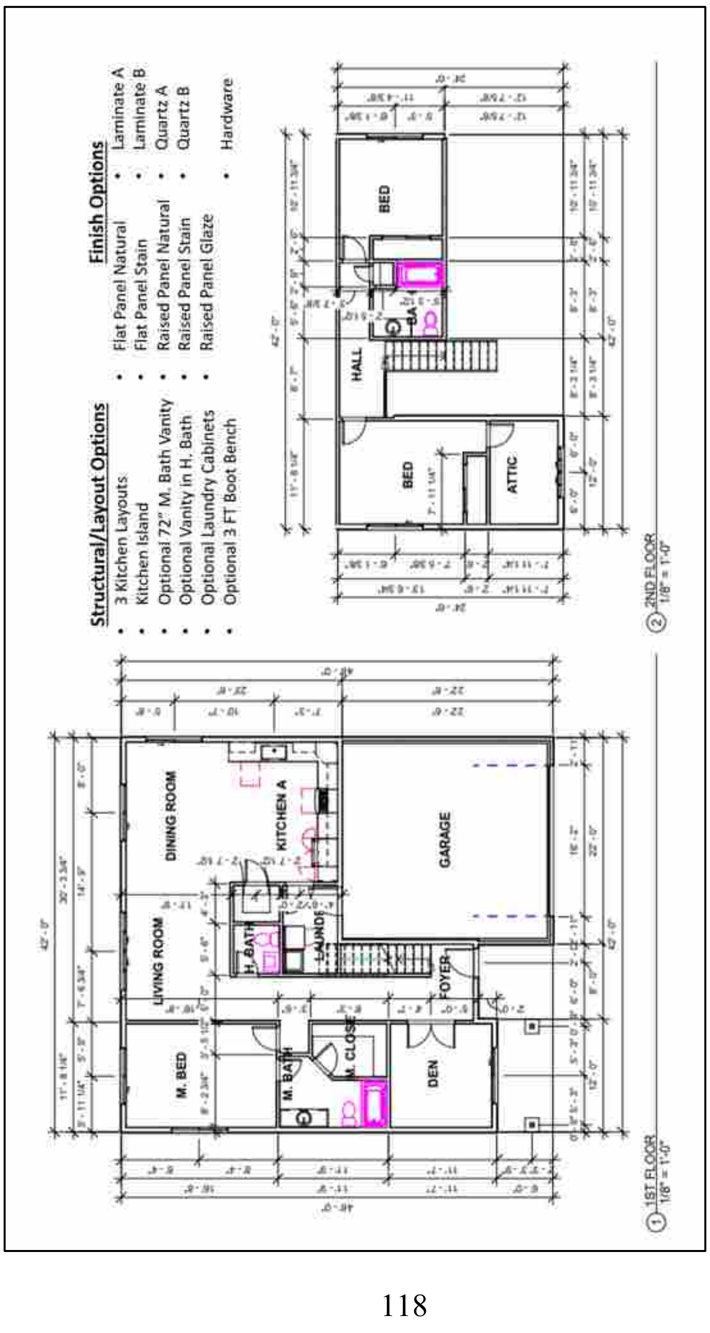
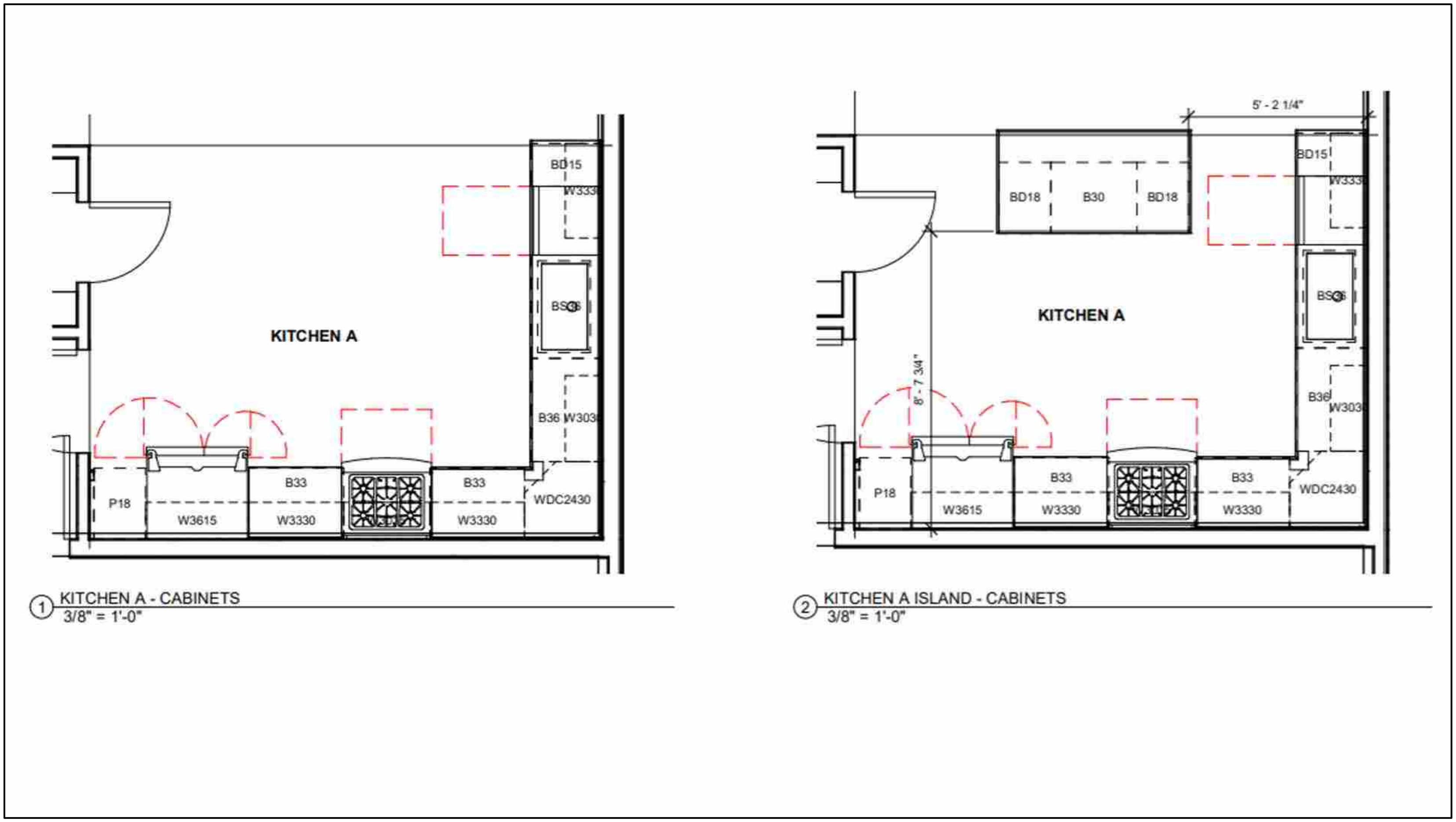
APPENDIX A SECOND ROUND PROCESS SLIDES

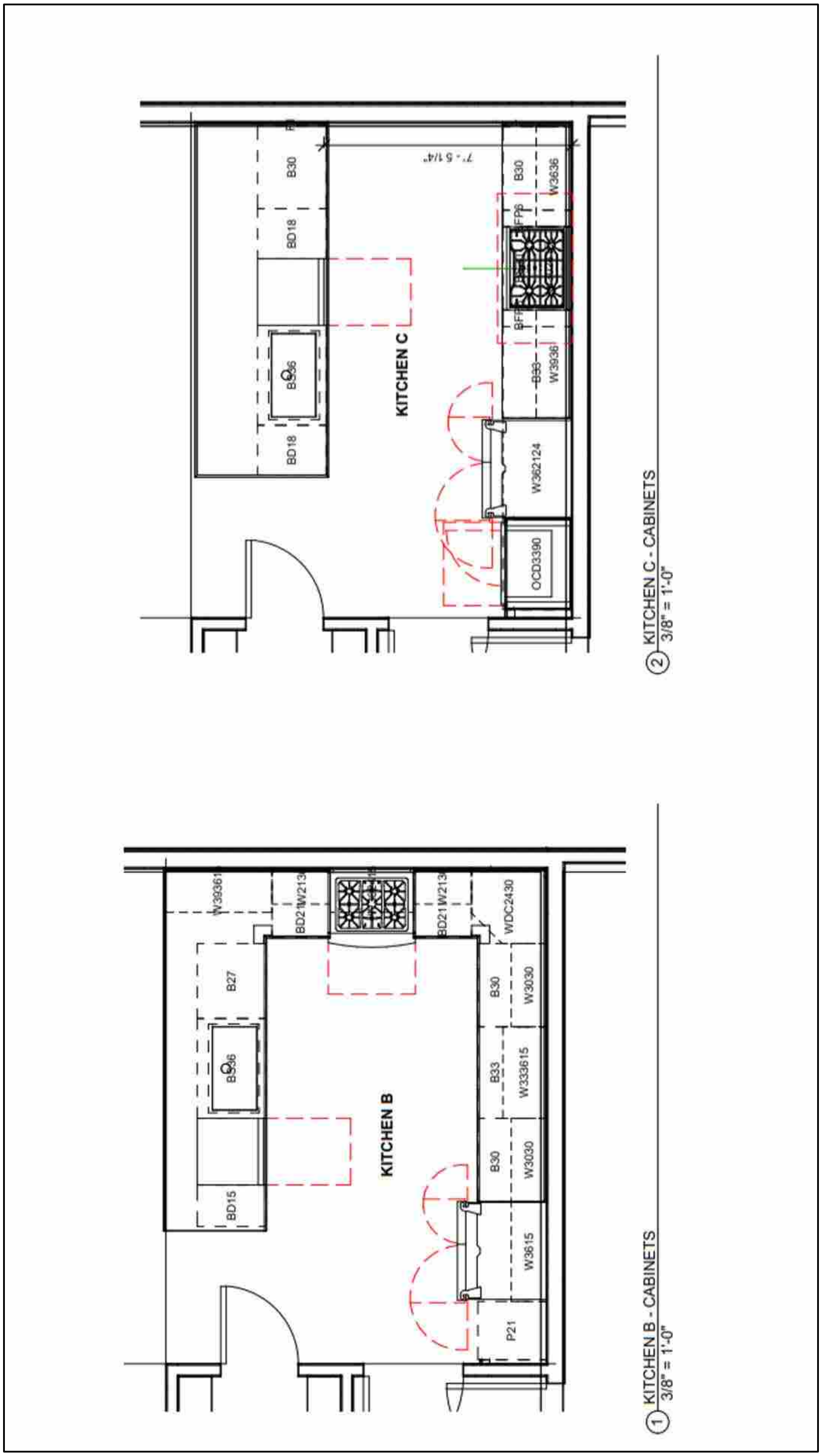
A.1 Slide 1 – Floor Plan



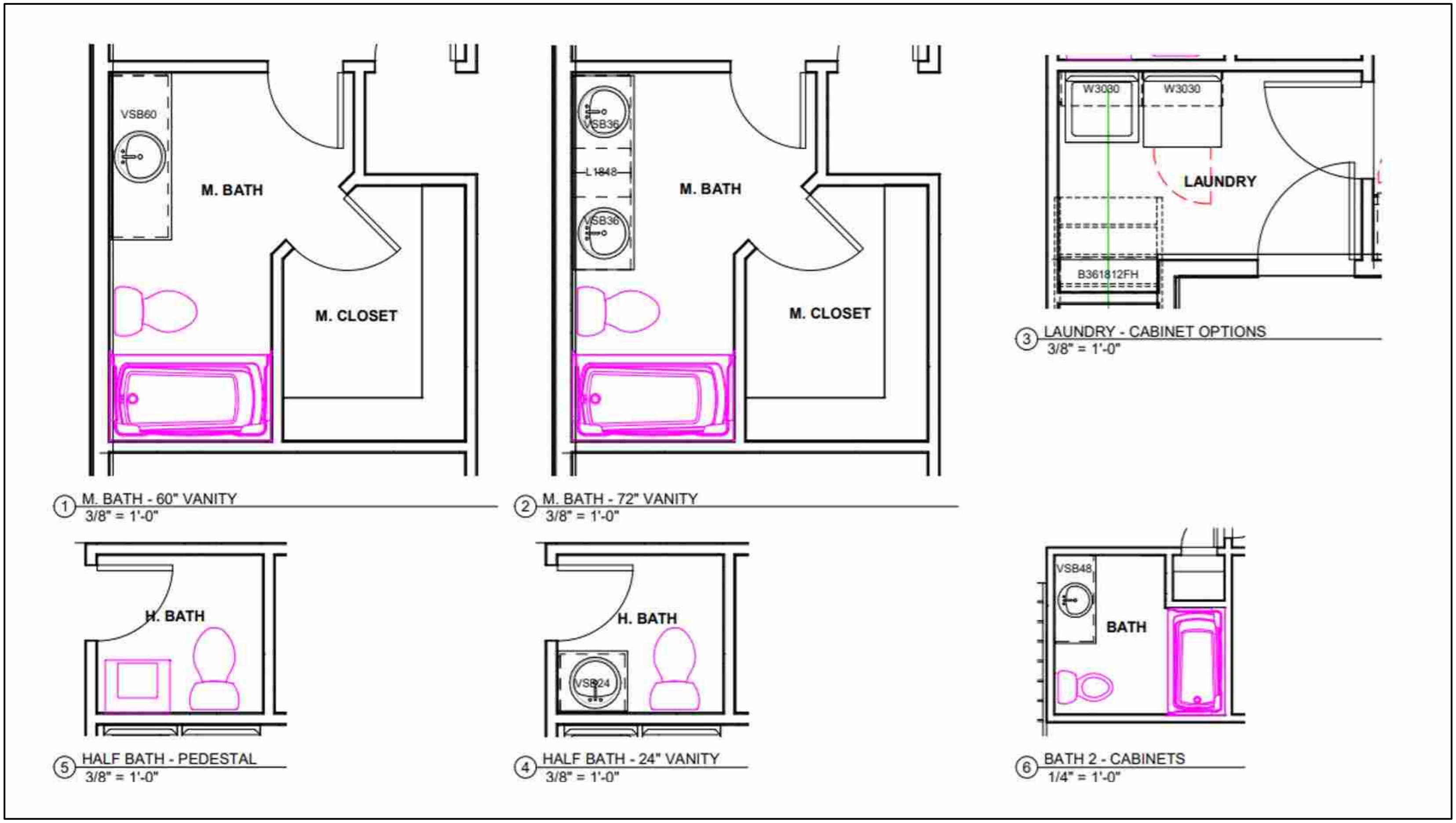
A.2 Slide 2 – Kitchen A and Kitchen A with Island



A.3 Slide 3 – Kitchen B and Kitchen C



A.4 Slide 4 – Other Cabinet Options



Structural/Layout Options

Option	Price	Alternate Pricing
Kitchen A Layout	Inc. Base	
Kitchen B Layout	$5,150	
Gourmet Layout	$3,050	
72" Master Vanity	$1,400	

Master Vanity Finish Options

Option	Price	Alternate Pricing
Flat Natural Cabinets	Inc. Base	
Flat Stained Cabinets	$100	
Raised Natural Cabinets	$280	
Raised Stained Cabinets	$420	
Raised Glazed Cabinets	$610	

Kitchen A Finish Options

Option	Price	Alternate Pricing
Flat Natural Cabinets	Inc. Base	
Flat Stained Cabinets	$600	
Raised Natural Cabinets	$1,850	
Raised Stained Cabinets	$2,750	
Raised Glazed Cabinets	$3,910	
Laminate A Countertops	Inc. Base	
Laminate B Countertops	$310	$7.75 / sf
Quartz A Countertops	$1,180	$30.75 / sf
Quartz B Countertops	$2,950	$77.00 / sf

Kitchen B Finish Options

Option	Price	Alternate Pricing
Flat Natural Cabinets	Inc. Layout Opt.	
Flat Stained Cabinets	$980	
Raised Natural Cabinets	$2,760	
Raised Stained Cabinets	$4,070	
Raised Glazed Cabinets	$5,800	
Laminate A Countertops	Inc. Layout Opt.	
Laminate B Countertops	$520	$7.75 / sf
Quartz A Countertops	$2,070	$30.75 / sf
Quartz B Countertops	$5,170	$77.00 / sf

Kitchen C Finish Options

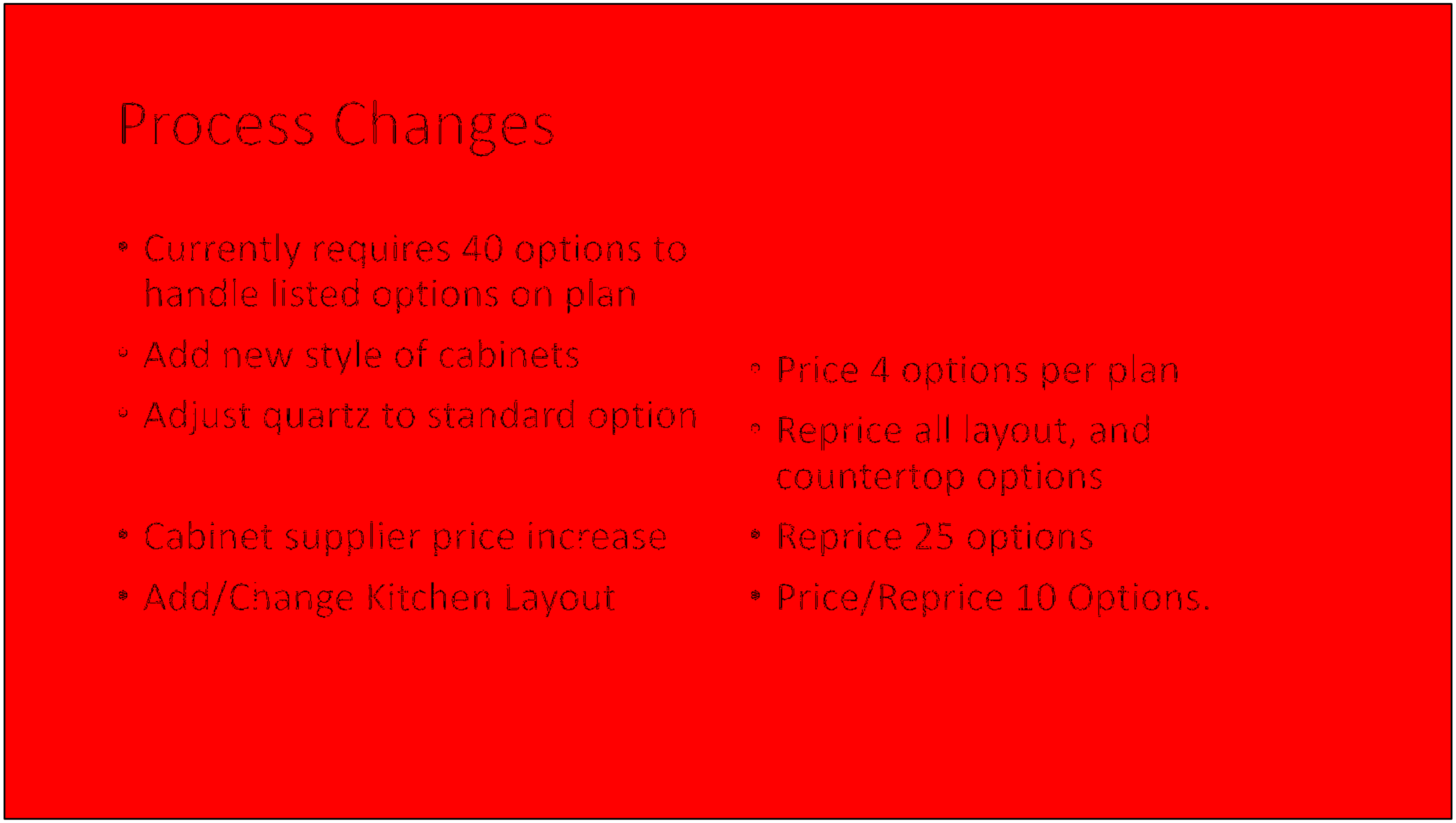
Option	Price	Alternate Pricing
Flat Natural Cabinets	Inc. Layout Opt.	
Flat Stained Cabinets	$750	
Raised Natural Cabinets	$2,170	
Raised Stained Cabinets	$3,050	
Raised Glazed Cabinets	$4,340	
Laminate A Countertops	Inc. Layout Opt.	
Laminate B Countertops	$510	$7.75 / sf
Quartz A Countertops	$2,040	$30.75 / sf
Quartz B Countertops	$5,080	$77.00 / sf

A.6 Slide 6 – Typical Preconstruction Process

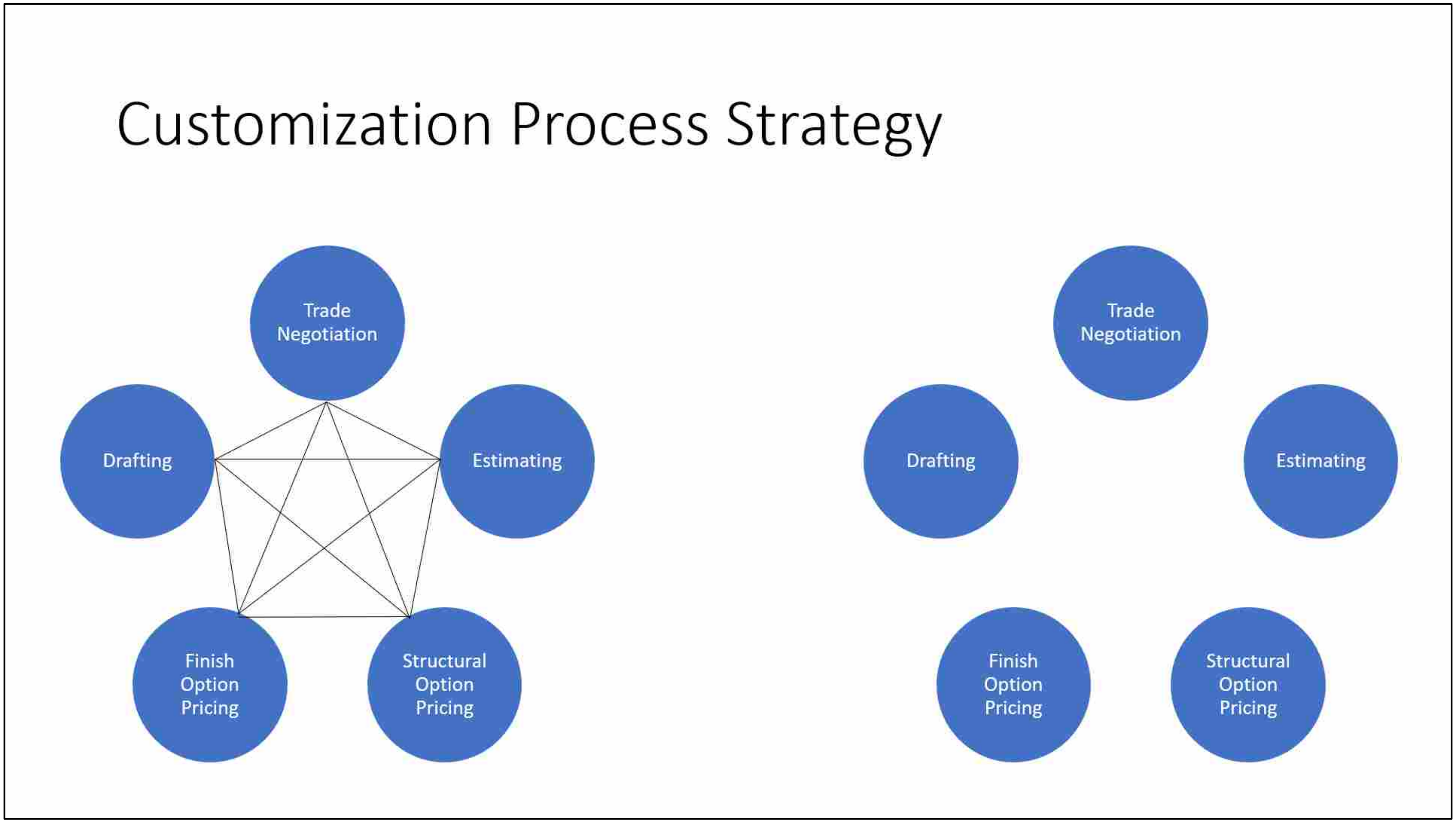
Typical Preconstruction Process

- Define Product as Plan
- Negotiate Trade Pricing Targeting Assemblies/Bid
- Build Master Plan Options Into System
- Define Master Planset (Some define holistically, some define as group of options)
- Define Master Planset Options
- Define Option Pricing Prior to Sale

A.7 Slide 7 – Process Changes

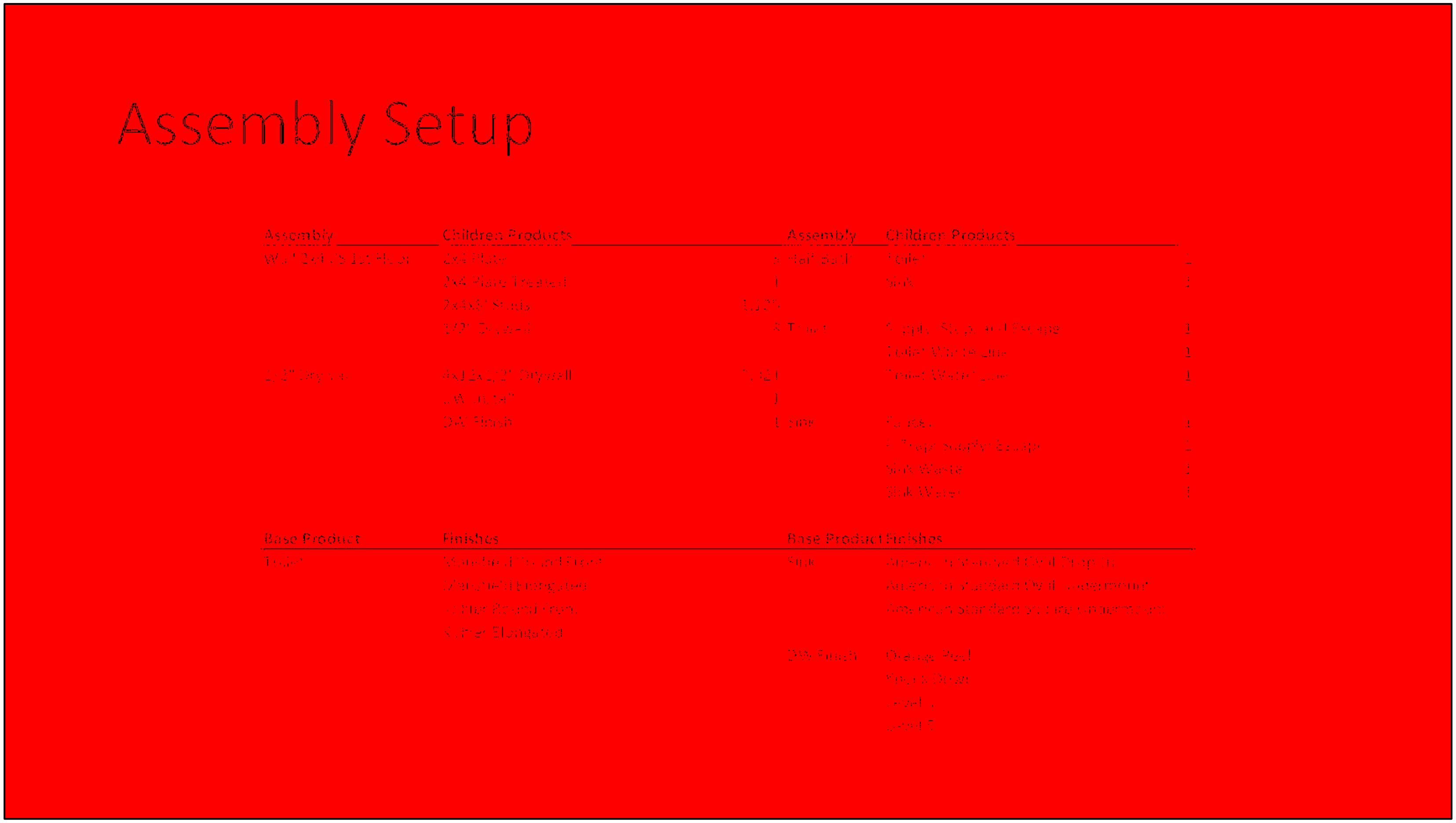


A.8 Slide 8 – Mass Customization Process Strategy

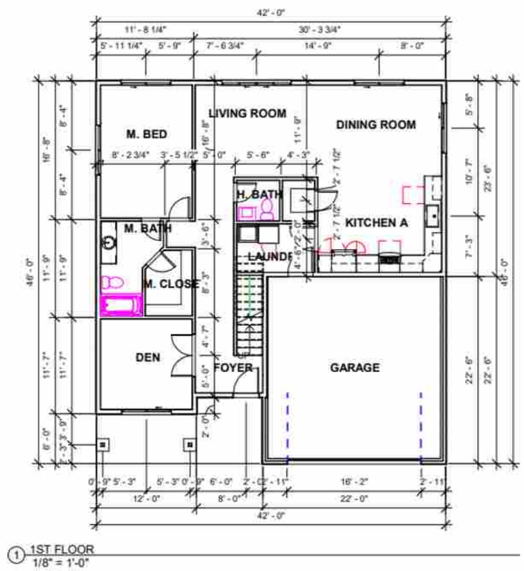


A.9 Slide 9 – Mass Customization Process Strategy (Cont.)

A.10 Slide 10 – Assembly Estimation Setup



Modular Structural / Layout Options



- Takeoffs are as Generic as Possible
- Model should be a consolidation of several options, not a cohesive whole
- Exclude Kitchen Cabinets/Countertops
- Flooring is Generic by Room
- Door are Generic by Size / Swing
- Foundation is part of Slab on Grade Option, not Model

Structural/Layout Options

Takeoffs are at Assembly Level

Exclude Finishes from Items

Standardize what is included in key areas of the house at a base level. Use Options to handle customization.

Separate Options that would need to be removed in another option

Base House

- Wall 2x4 0S 1st Floor
- Wall 2x4 1S 1st Floor
- Wall 2x4 2S 1st Floor
- Wall 2x6 0S 1st Floor
- Wall 2x6 1S 1st Floor
- Wall 2x6 2S 1st Floor
- Door 2468L
- Door 2468R
- Door 2668L
- Door 2668R
- 1st Floor SQFT
- Half Bath

Kitchen A	
B12	1
SB36	1
BCR36	1
B27	1
BD15-3D	1
Countertop Area	37
Kitchen Sink	1

Slab on Grade Foundation

- 6"x4' Foundation Wall w/ Footing
- 8"x4' Foundation Wall w/ Footing
- 10"x4' Foundation Wall w/ Footing
- Foundation Insulation LF

Basement Foundation

- 6"x4' Foundation Wall w/ Footing
- 8"x4' Founation Wall w/ Footing
- 10"x4' Foundation Wall w/ Footing

Structural Option Pricing (Automated)

Base Assembly	Qty	Sub Assembly	Qty	Final Estimate	Qty	Unit Cost	Cost
Wall 2x4 0S 1st Floor	24	2x4 Plate	72	2x4 Plate	72	0.38	$ 27.36
		2x4 Plate Treated	24	2x4 Plate Treated	72	0.52	$ 37.44
		2x4x8' Studs	27	2x4x8' Studs	27	2.38	$ 64.26
		1/2" Drywall	192	4x12x1/2" Drywall	4	15.92	$ 63.68
				DW Install	192	0.24	$ 46.08
				DW Finish (Orange Peel Std)	192	0.37	$ 71.04
Assembly Subtotal							$ 309.86
Half Bath	1	Toilet	1	Toilet (Mansfield Round Std)	1	120	$ 120.00
				Supply; Stop; and Escape	1	27	$ 27.00
				Toilet Waste Line	1	250	$ 250.00
				Toilet Water Line	1	250	$ 250.00
		Sink	1	Sink (American Std Drop-In Std)	1	63	$ 63.00
				Faucet (Delta Core B Single Std)	1	80	$ 80.00
				P-Trap; Supply; Escape	1	27	$ 27.00
				Sink Waste	1	250	$ 250.00
				Sink Water	1	250	$ 250.00
Assembly Subtotal							**$ 1,317.00**

Default Finish is used for Structural Option Pricing

Subassemblies let you change estimate calculation in an isolated location

A.14 Slide 14 – Finish Option Pricing (Automated)