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# ONE SIZE DOES NOT FIT ALL: RETHINKING APPROACHES TO MANAGING THE CONSTRUCTION OF MULTI-STORY APARTMENT BUILDINGS

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## ABSTRACT

For multi-story apartment buildings, the “product” that customers value has two distinct components: shared (exterior and shared internal spaces) and private (individual apartments). The basic elements are the same (flooring, plumbing, etc.), and they are installed by the same trades using the same work methods. Yet the shared and private components are fundamentally distinct; the former entails repetitive work packages with stable design and process information, whereas the latter has high variation between products, for which information arrives in an unpredictable fashion as customers make final decisions about interior finishes. Although this dichotomy has been identified in the literature and its deleterious effects studied, construction management has ignored it and attempted to manage both project types within the same production system and by using similar management tools. In this paper, we explicate the shared/private delineation drawing on analogies from manufacturing processes (such the Mass vs. High-Mix, Low-Volume distinction) and discuss appropriate management tactics to address the inherently dual nature of the integrated final product.

## KEYWORDS

Construction management theory; High-mix, low-volume (HMLV); Information stability; Product mix; Production system design.

## INTRODUCTION

Application of a single uniform production system to the process of managing the construction of multi-story apartment buildings, in which each apartment is sold to a different customer, is both ubiquitous and wasteful. Customers desire to make changes to the “standard” design in order to customize the apartment to their own particular needs and budget. Many developers of projects of this type make it possible for customers to do

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so, staffing "client change departments" that work with customers to make the requested changes.

In principle, this phenomenon is very much in line with Lean thinking. Womack and Jones (2005) proposed the concept of "Lean Consumption" to reorient providers of goods and services around the needs of their customers. Among their "Principles of Lean Consumption," they state: "Provide exactly *what* the customer wants". The trend toward "mass customization" (Pine 1993) is ubiquitous in modern industry as consumers become more discerning and the number of option they can choose from multiplies apace. However, in construction, the desire to honor the requests of each particular customer leads to problems in the process of construction as traditionally managed.

# BACKGROUND

Each customer makes a series of changes to the standard design, which are then translated into the blueprints or BIM model of the building, so that shop drawings for the trade subcontractors will have the correct information (Kamara et al. 2002; Rocha 2011; Sacks and Goldin 2007). The authors interviewed the manager of a "client changes office" for a construction project with 1,038 apartments arrayed in 20 buildings and obtained from them the full list of over 65,000 client changes. A large amount of variability was found in the extent of changes, as shown in Figure 1. Note that the number of apartments without changes was just 5.3% of the total.

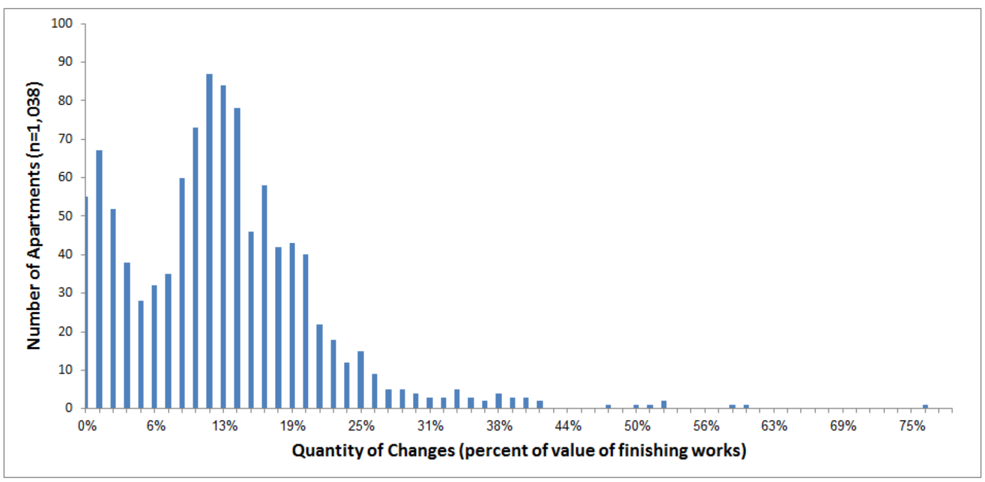



Figure 1: Histogram of quantity of customer changes in sample project.

Permitted changes to the apartment are bounded by various constraints imposed by the building design and or building codes. But within these constraints, the permitted changes are so numerous that their combination leads to effectively unbounded permutations. Some of the popular changes made in the exemplar project include adding, removing, or changing the "standard" fixtures, interior walls, materials.

While the customer changes are measured against the standard design by the client change department, during the construction phase, there effectively is no standard; the vast variety means unique shop drawings must be provided for every single apartment. Subcontractors are hard-pressed to describe exactly what the "standard" consists of.

The wide variation of configurations leads to a high level of variance of the work content for each apartment. One apartment might have many complex additions, while its neighbor has few. Shop drawings were pulled by the subcontractor on a "Just in Time" basis before beginning work on each floor. This means that the actual amount of work only became clear at a late stage in the project. Varying work content, especially when exposed late in the process, creates inefficiencies in the work as performed (Tommelein et al. 1999). Sacks and Harel (2006) described how the actors in a construction project (GC, Subs) react to variability as each seeks to maximize its own utility. Ultimately, many of these tactics lead to global inefficiencies.

Customer changes contribute to "noise" in the production system in other ways. If the customer has not made up their mind by the time the construction has progressed to their floor of the building, the information of what to build in their apartment will not be complete. This could lead to a situation in which the apartment is "skipped" with the construction progressing to the next floor, requiring backtracking in the future. A delay could also be caused by custom materials not arriving on time. Second, if the customer "changes his/her mind" once the construction is underway, rework must be performed on the apartment. The shuffling of subcontractors to make the rework happen will also negatively impact the scheduling.

The customer change processes, while intended to create more value, actually tends to create waste in the traditional construction management paradigms, in which the interior finishing works progress one floor a time up the building.

## ETO, MTO, MTS PRODUCTION SYSTEMS

Sharman (1984) proposed managing the supply chains of different types of products by the amount of customization offered to the customer. The point at which the customer order enters the supply chain, referred to by Sharman as the "Order Penetration" point and Hoekstra et al. (1992) as the "decoupling point", is where forecast/planning-driven production transitions to customer order-driven customization. Today it is commonly known as the Customer Order Decoupling Point (CODP), and its location separates supply chains into different types (Olhager 2010):

Make-to-stock (MTS)

Assemble-to-order (ATS)

Make-to-order (MTO)

Engineer-to-order (ETO)

The different CODPs that define the supply-chain types listed above punctuate the phases of product creation that Olhager (2010) lists: Engineer (design), Fabricate, Assemble, Deliver. In construction, the distinction between fabrication and assembly is much less distinct than assumed in other industries. Various building materials are both fabricated and assembled off-site and then brought to the construction site where another mix of fabrication and assembly ensues. Thus it is harder to delineate a construction project into the same clear “fabricate then assemble” stages. A better formulation for construction is therefore:

Engineer/Design

Off-site fabrication/assembly (to the extent that it exists in each particular project)

On-site fabrication/assembly

Deliver

Though it is not explicitly stated, it is implied in Olhager’s analysis that at the CODP, the supplier receives both a commitment on the part of the customer to purchase the product as well as full information about exactly what product configuration is desired. For example, in MTS, the customer comes to the store, picks the product off the shelf, and takes it to the checkout counter. In ATO, the customer sends an order with both the desired components and information about how they will pay their bill. In multi-story apartment construction, the two components are not always received at the same time; the commitment to purchase an apartment in a new housing project can be made much earlier than when full information about design choices is supplied. For the purpose of this analysis, it is important to realize that it is the receipt of information which is critical to the construction process.

### CONSTRUCTION PRODUCTION SYSTEMS

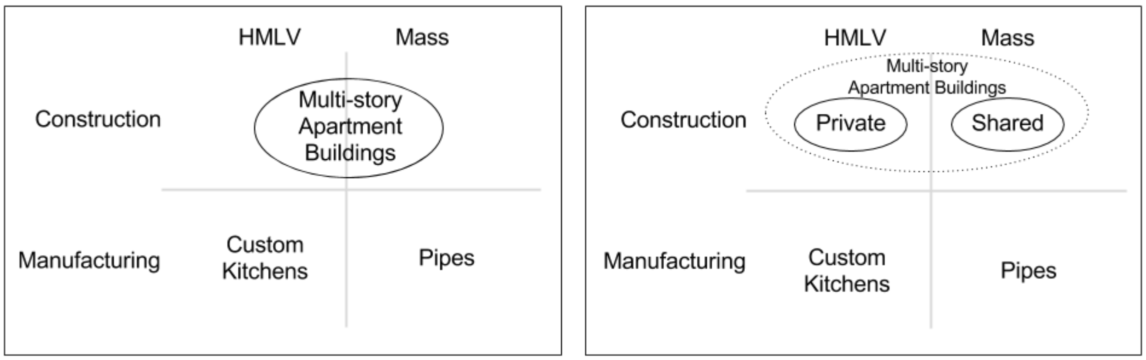
Lean Construction thinkers have given much thought to how construction relates to other forms of production (Ballard and Howell 1998; Ballard 2005; Koskela 2000). The general consensus is that though there are degrees of overlap, and even suggestions that one might be a “special case” of the other, construction is distinct from “manufacturing”.

Manufacturing can be deconstructed (Schmenner 1993) on a scale from job shops that produce a wide variety of product using a mix of processes to dedicated mass manufacturing lines. The implicit level of analysis when looking at construction is at the level of the project. At this Level of Detail, construction is rightly placed closer to the one-off side of the manufacturing scale.

The authors of this paper take a different approach, suggesting a two-axis model, and drilling down to within the project itself to identify which elements can be more closely identified with which types of manufacturing. Figure 2a depicts this model, including where we identify multi-story apartment buildings to be located on these axes. Given the fact that we identify this type of project to straddle two quadrants (since the customized apartments are closer to HMLV whereas the shared elements are repeated from floor to floor), we suggest splitting the project into two, as shown in Figure 2b. This bifurcation is discussed at greater length below.

## TRADITIONAL PRODUCTION SYSTEMS FOR MULTI-STORY APARTMENT BUILDINGS

The problem with the construction of customized apartments in multi-story buildings is that the process does not follow a linear “Design - Build - Deliver” progression. The customer changes represent a form of design occurring during the construction, so the progression is closer to: “Design - Build - Design again - Build some more and correct errors - Deliver”. Rather than a simple linear process, there is a loop in the process from “Build” back to “Design”, representing additional complexity requiring additional resources. This rework loop is a form of re-entrant flow, with the latter's attendant wastes of delays and additional costs. The unpredictable variability of the work content negatively impacts the ability to plan and execute smoothly, creating more delays.




(a) (b)

Figure 2: (a) A two-axis view of different production methods, including the location of Multi-Story Apartment Buildings in this model. (b) Splitting Multi-Story Apartment Buildings into two sub-projects.

Paulson (1976) theorized about the cost of changes to the design at different points along the timeline of a project. At the beginning, the designer has maximum influence to change the design and the costs of change are small. But as time goes by and the project progresses, more execution costs are sunk and more product is built, and the cost of change goes up exponentially at the same time that the scope of possible changes goes down. Paulson’s curve has traditionally been understood as an admonishment to “front-load” the design process. In the scenario described above, design is being attempted once the project is well underway. The attendant costs are, as Paulson predicted, high. In the terminology of Sharman, both the building and apartment are Engineered-to-Order (ETO), but the engineering is scheduled to take place at two different stages.

## PRODUCT TYPES IN MULTI-STORY APARTMENT BUILDINGS

The question is, “Are the inefficiencies inherent in building customized apartments in multi-story buildings an unavoidable part of the practice, or are there management tactics that can be adopted in order to improve?” We suggest the latter, in the form of an alternate production system design.

The trivial solution to the problems caused by variations in apartment configurations is to forbid customers from making any changes, and sell the standard apartments “as is” in an off-the-shelf approach (MTS). However, for a purchase as costly as an apartment, it is unrealistic to expect that customers will be satisfied with standard options. In addition, this is not in line with Womack and Jones (2005)'s Principles of Lean Consumption.

We return to the issue of information, and in particular its stability. The “product” that the end customer purchases from the developer is composed of two components that are markedly different in terms of their information stability. The first component is a shared component: the building exterior and structure, the lobbies, the parking garages, the utility mains and shared service systems. For these elements, the information is stable by the time the construction phase begins. The second component is a private component: the interior of each customer’s apartment, replete with all the customizations they have chosen to turn the standard apartment into their own conception of “home.” For this element, the information (across the project) is much less stable. Each customer will make their own set of changes and adaptations, which means that the project will be comprised of almost as many configurations of apartments as there are units in the building. Also, the arrival of the information adds another degree of instability, since different customers might make their choices at different times.

Table 1: Differences between the Two Sub-Components of the Productive

| Feature | Building (Shared) | Apartment (Private) |
|---|---|---|
| Client | All customers, municipality | Single customer |
| Production System Type | Mass | HMLV |
| Variability | Low | High |
| Information Stability | High | Low |
| Location Breakdown | Multiple sets of similar locations | A single location |
| Location Work Content | Uniform | Unique |

## TWO DISTINCT AND SEPARATE PRODUCTION SYSTEMS

When viewed through this information-stability-based lens, the differentiation between the shared and the private is stark: the shared component bears resemblance to a “mass manufactured” product; the private component is more like a “high-mix, low-volume” (HMLV) product. Industrial engineers recognize that mass-manufacturing production lines must be managed very differently from HMLV job shops. Thus we propose that in construction, the project be split into two sub-projects, with the two sub-components managed separately. The first sub-project is focused on the shared components of the product - exterior, common systems, shared spaces like lobbies. The second (really a series of smaller sub-projects) is focused on building the private components of the product - each apartment’s individual interior.

This rationalization will allow each sub-project to be managed in a production system tailored to its particular characteristics, rather than trying to force two dissimilar products through the same management pipeline.

## WHOLE BUILDING PRODUCTION SYSTEM (SHARED SUB-COMPONENT)

The first sub-project, the shared components, is characterized primarily by the stability of the information. The work content on each floor (barring radical shifts in cross-sectional area of the building, which are less typical in multi-story apartment buildings) is similar, since the exterior structure and the lobbies and systems are “copy-paste” one on top of the other. This informational stability and repetitiveness are reminiscent of mass-produced products made in a factory, and appropriate management tactics can be adopted from this field. Takt-time planning (including work balancing) and the Line of Balance method of planning and production control are very much relevant for the shared components of the product, since the repetitiveness of the work packages lend themselves readily to line balancing and remedial measures if deviations are detected. Likewise, from a Lean point of view, the repetition of work content is very much suited to Kaizen continuous improvement, as there are both repeated opportunities from floor to floor to identify the wastes and attendant opportunities for improvement, as well as the possibility to measure the impact of the countermeasures in ensuing floors.

## APARTMENT PRODUCTION SYSTEM (PRIVATE SUB-COMPONENT)

The second sub-project, the particular apartments, has little information stability, both when viewed across the project and chronologically. Work content in each apartment varies in accordance with the fancies of each individual customer, and it is very possible that the order that each finalizes their decision does not follow the orderly floor-after-floor progression that the structure is constructed in. In fact, it is entirely possible that some of the apartments will not be sold before the construction of the structure concludes; in that situation, building a “standard” MTS apartment also does not create the maximum value for the end-customer who might desire a completely different configuration. Given these instabilities and the costs associated with changing the design late in the construction process, we propose that the construction be commenced only after the information for each apartment is stabilized - that is, only after the customer has made up his/her mind. In this we continue the approach of Sacks and Goldin (2007) and Sacks et al. (2007), who showed the wastes caused by “pushing” apartments into construction before their information is made ready, instead recommending an approach more closely aligned with the Last Planner System (Ballard 2000), which seeks to shield work crews from work packages with unfulfilled prerequisites including design information, and in this way deal with the variation and variability inherent in this sub-component.

Drawing the parallel to traditional manufacturing for the private sub-component of the product, we see it is a HMLV product. The vast number of possible apartment configurations means that the variety (mix) will be high, while the number produced of each type (production volume) will be low. In an HMLV environment like a job-shop that is capable of making a wide variety of products, there is very little repetition, so the Lean principles and techniques have to be adapted appropriately. Lane (2007) and Duggan (2013) have written extensively on Lean tactics in HMLV, and many, like use of Visual Management tools to manage the information flow for the construction process and Value Stream Mapping for common/representative processes, will be familiar to Lean practitioners.

## ADVANTAGES

This deconstruction of the project into two allows optimization of each individually in accordance with its own particular characteristics. The shared component can proceed apace without having to try to deal with the variation and instability introduced by the private components; the latter can be commenced only after all preconditions are met (including having the particular materials the customer has requested on hand), rather than being pressured to start according to the progression of the structure, since premature work commencement is a recipe for rework. With all prerequisites ticked off, the apartment can be completed rapidly and smoothly.

Interestingly, though the two sub-projects are distinct in the ways described above, they are both Engineer-to-Order. What the division does is allow each fulfilment stream to be properly conducted as such: concluding the design phase before beginning the fabrication, on its own timeline. And it is expected that each component will be able to shrink its lead time, which will allow a time-based competitive strategy in the market (Suri 2010). The shared component is to be tasked with a clear goal: attaining a certificate of occupancy as quickly as possible. Any delay of the shared components of the building is a delay for all of the customers together. The private components are also charged with putting an emphasis on timing; preparing all prerequisites so that no time is wasted on waiting once the work is begun. Multi-skilled teams of subcontractors (Sacks and Goldin 2007) who can jointly complete all of the work on the apartment will further simplify the management of many different apartments while reducing the lead time of each apartment.

## CHALLENGES

In order to realize this approach, it is likely that various engineering and bureaucratic hurdles will have to be overcome. On the technological side, it may be possible to draw inspiration from the standardized interfaces between the "infill" and "support" of the Open Building system (Habraken and Valkenburg 1999). Another challenge may be creating the organizational structures necessary to support this new way of constructing. Presumably, as soon as the "shared" parts of the building are completed, many of the customers will want their apartments to be constructed as soon as possible thereafter. This calls for a large number of workers to perform these finishing works. Large peaks in production volume are a form of *mura* or "unevenness" (Womack 2013 pp. 107–109), and represent a form of waste in the Lean paradigm. One way of dealing with them while still meeting the customer requirements would be to "zoom out" from the scope of one particular project, and take a regional/national view of the construction industry in total, aggregating many projects together (Bertelsen and Sacks 2007). A company that could provide apartment finishing services to many different buildings could possibly have the production capacity to deploy in rapidly completing many apartments simultaneously in one building before transferring the workforce to the next building. This would allow the reduction of *mura* while still "provid[ing] what's wanted where it's wanted exactly *when* it's wanted" (Womack and Jones 2005). This hypothetical "apartment provider" could utilize a logistics center that serves both as a cross-docking location between material suppliers and containers filled with all of the material for each individual apartment as well as a "design center" where the customer arrives to choose among various materials and fixtures while finalizing the apartment layout. This latter function would be similar to the "one stop sales center" pioneered by the Doyle Wilson Homebuilder company described in Womack and Jones (2003 p. 29).

An implication of this new organizational structure is that the "apartment supplier" is no longer limited to new construction: the same supplier could provide a "gut and refurbish" service to owners of apartments in existing buildings. Further, the same supplier could provide apartments to buildings for which the shared sub-component is built by a competitor; the bifurcation of the product into two sub-components allows the customer to choose the supplier of each sub-component separately to reflect his/her particular needs.

## CONCLUSION

There is a clear dichotomy between the two sub-components of the product, the shared and the private in the context of a multi-story apartment building. An analysis of variability and the timing of information reveals significant differences between these two. The logical conclusion, given the differences identified, is to separate the production approaches for the two subcomponents, instead providing production systems tailored for each type of sub-product.

This research is limited to construction projects that share the one-to-many relationship between the built project and customer base. A limitation to future implementation is that the resulting systems require deep changes to the commercial alignment of the industry. The production system alternatives developed will need thorough testing, either in simulation or field experiments.

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