1.3. Designing Context-Aware Construction Systems

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Abstract
Digital frameworks for user participation in the design of affordable mass housing are being reconsidered as a co-design method to provide context-specific solutions. These methods are particularly relevant for interior renovations, whose frequency is likely to increase because of the move to homeworking, and already account for a substantial part of the carbon emissions over a building's life. In the context of the climate emergency, this requires rethinking building workflows, and open-source digital frameworks are proposed to address the need to develop specific solutions for local contexts. This essay discusses design principles for the mass customizable construction of partition walls.

Key words: mass customization, building renovation, co-design, partition walls

The notion of leveraging digital frameworks to enable user participation in designing the built environment has its roots in the sixties, and is being reconsidered now due to developments in artificial intelligence (AI), computational design, and digital fabrication. It is a revision of the modernist utopia of providing affordable housing to generic clients, replacing the top-down design methods that provide one-size-fits-all solutions with co-design methods mediated by digital systems to provide context-specific solutions to its users.

Ongoing digitalization trends have been accelerated by the COVID-19 pandemic, with implications such as the move to homeworking, long foreseen by Alvin Toffler (1980). Such change will affect all aspects of the built environment, from the way cities and houses are structured to the way construction is practised. Reintroducing work in the home will likely increase the incidence of interior renovations which already accounts for a significant part of the carbon emissions over a building's life (Addis & Schouten, 2004: 38; Sturgis, 2017).

To address the above trends in the current context of climate emergency, a fundamental shift in how buildings are procured, designed, constructed, (re) used, and demolished is required. The problem is urgent and widespread. The required solutions should be specific for local contexts based on sustainability criteria; hence the design methods should be based on distributed open innovation to develop the building systems. Open-source digital frameworks can provide a solution to enable the design, fabrication, delivery, and reuse of systems, components, and materials (Ratti & Claudel, 2015: 105). The present article details design principles for mass-customizable and disassemble-able construction systems of partition walls for building renovation.

Democratizing Design through Computer Means

In 1969, Yona Friedman (1971) devised a proto-computational system to enable user involvement in the design process. The Flatwriter, a modified typewriting machine, would allow a future resident to design a flat to be built with prefabricated components such as partition walls, bathrooms, and kitchens. The user-designer would be granted the freedom to express preferences while the task of the architect, the designer of the system, was to warn the user and society of the consequences of the choices.

Concurrently, Nicholas Negroponte (1969) was hypothesizing human-machine collaboration in architectural design to expand the scope of architectural design services. From 1973 to 1975, Friedman collaborated with Negroponte on the Architecture-by-Yourself project, which resulted in YONA, an interactive application implemented on a computer with a touchscreen interface for non-experts to configure their apartments (Weinzapfel & Negroponte, 1976).

The idea of allowing users to control the design of their products is also at the root of the "mass customization" (MC) production and business strategy (Davis, 1987). It is an alternative mode of production that reconciles the contradictory goals of mass and custom production, and whose main enablers are computational design, digital fabrication, and the web. While MC immediately captured the imagination of architects for the possibility of exploring formal universes of design (Carpo, 2017: 58), a distinct application to "the long tail"[1] of the construction industry is now gaining relevance (Kolarevic & Duarte, 2019). In this application, the user context, in all its dimensions, is the key driver of the customization process. Configurators, product platforms, and modularity are important concepts to enable the implementation of the mass customized construction (MCC) paradigm.

MCC is founded on the premise that design variation may be objectively described by several parametric or rule-based systems. To address the challenge, the "meta-designer" must reduce the scope of the system to a specific typology and construction system; provide proper methods for mediating the objective description to allow the "instance-designer" to navigate the solution space; select the appropriate level of automation balancing cost, social, and sustainability issues; set the level of instance-designer control, balancing predictability and quality of designed solutions, and the complexity of the configuration process (Kolarevic & Duarte, 2019).

The goal of MCC is not to deliver complete freedom to the end-user but to enable the possibility of personalization of housing to clients that could not otherwise afford it, contributing to a more diverse, inclusive, and resilient built environment. Perhaps unsurprisingly, its proponents frequently draw on vernacular construction systems and building typologies as their inspiration for developing digitally fabricated construction systems (Sass & Botha, 2006; Benros *et al.*, 2011; Parvin, 2013).

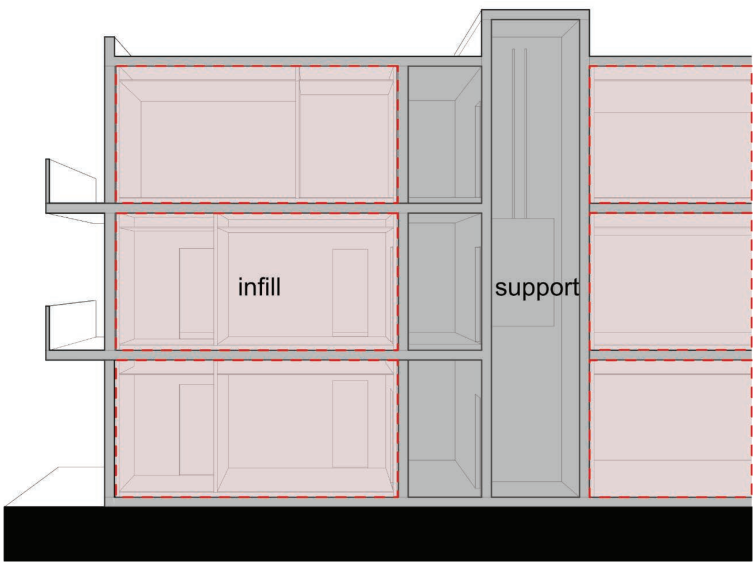
Yet, simply reinstating, updating, or converting traditional construction methods to current digital fabrication tools is not enough to ensure adequate responses to contemporary challenges. In addition, although most digitally fabricated buildings can be disassembled, the reuse of systems, components, and materials in different configurations from those originally designed is often difficult or impractical. The solution seems to rest on redesigning the design process, "considering the built environment as an autonomous entity" that evolves over time with specific patterns (Ratti & Claudel, 2015: 104).

Habraken's Legacy to Mass Customized Construction

The social and economic advantages of the MCC paradigm have affinities with the ideas of separation of support and infill, which John Habraken has advocated since the 1960s, and which eventually became known in the 1980s as "open building". Habraken was one of the first authors to identify the problem of a lack of user participation and propose a systematic and holistic solution for the design, construction, and management of customizable mass housing (Habraken, 1972: 56).

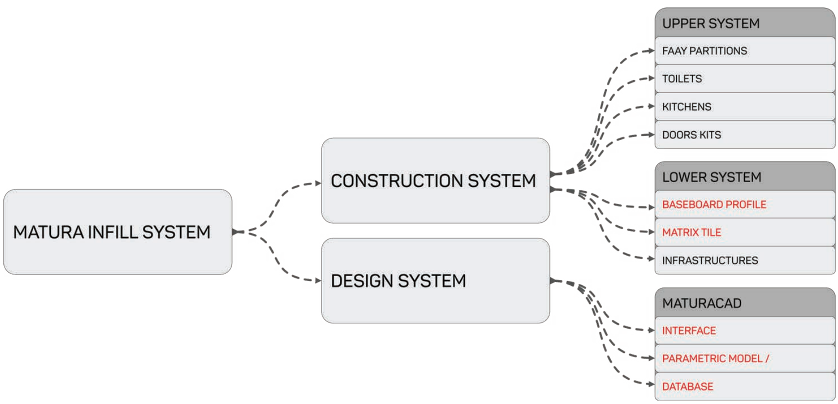
Habraken (1992) argues that the adoption of open building principles, such as the separation of technical systems at their interfaces, allowing replaceability with minimal disruption, is a precondition for the industrialization of construction and a greater degree of control over design by the user. He further states that user involvement is more important in decisions about the sub-systems for the infill of the building (*Figure 1*), where building elements such as partitions walls are changed more frequently. This was one of the factors that led Habraken and the Ahrend group to develop the Matura system between 1986 and 2000 (Kendall, 2015: 136).

Figure 1. Support and infill. The support consists of the building systems that are common to all buildings, e.g. slab, façade, roof, elevator shafts, floor landings; infill comprises all the building systems that are specific to a single horizontal property, e.g. partition walls, dropped ceiling, raised floors, and all services to one apartment.



The Matura Infill System was developed for the renovation of mass-housing apartments (Kendall, 2015), and was a precursor of present MCC systems. It comprised a construction system that combined off-the-shelf building systems with coordination components and a computer system, the MaturaCAD. In the last of its two iterations, the MaturaCAD was an interactive design interface allowing the manipulation of parametric component representations to operate in tandem with the clients to customize their apartments. The system would then prepare the final design for prefabrication and the documentation for on-site assembly. It was an integrated and open system for sharing the control of design and production between the several stakeholders, yet the process was still vertically integrated in one company holding the patents of the components that made it work (*Figure 2*).

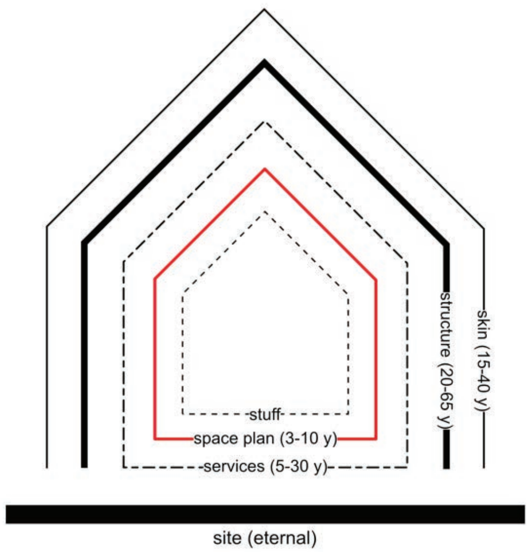
Figure 2. Matura Infill System was composed of construction and design systems. The construction system was divided in an upper system, composed of off-the-self components and subsystems such as the Faay partition wall, and a lower system, composed of a baseboard profile to support the partition walls and run the electrical and telecommunication cables, and the Matrix tile, used to organize water and sewer plumbing.



Independently of the commercial failure of the Matura Infill System, Habraken's ideas helped cement the notion that buildings are complex entities, whose parts evolve on different time scales and thus should be separable at their interfaces. These ideas have been expanded, by Francis Duffy (1990) as the theory of layers, and by Stewart Brand (1994) as the six S's (Site, Structure, Skin, Services, Space plan and Stuff), also known as the shearing layers of change (*Figure 3*). Within Brand's framework, partition walls are part of the space plan that is the most frequently changed system and with the higher number of dependencies with the other levels.

Elma Durmisevic (2006: 112) argues that simply focusing on a specific number of levels is misleading since these can be recursively divided into systems, components, and materials, each with a specific durability which may be different from the use lifecycle of the levels they are part of (Durmisevic, 2006: 112). Hence, there is a strong case for making all systems of a building decomposable into their most basic constituents, since doing so would maximize the opportunities for reuse at all levels of the technical decomposition of building systems. Such is the aim of the "design for disassembly" (DfD) methodology, which attempts to define principles for the design of interfaces between materials, parts, components, and systems; and the relations between the elements of each of the levels.

Figure 3. Shearing layers of change: a concept introduced by Francis Duffy (1990) for interiors and expanded by Steward Brand to the building level to describe the different rates at which different building subsystems change. Figure adapted from Brand (1994: **13**). Reproduced with permission of Stewart Brand.



Philip Crowther identifies a comprehensive set of principles for designing buildings or construction systems that are disassemble-able. They can be summarized as: (1) reversibility of assemblies and sub-assemblies into basic materials, (2) avoiding chemical connections between different materials, (3) minimizing the number and types of different components and connectors, (4) using lightweight recyclable or recycled materials, (5) prefabricating sub-assemblies, (6) increasing interchangeability, (7) using construction technologies that are compatible with standard building practice and common tools, (8) increasing serviceability, and (9) documenting the construction process (Crowther, 2009: 230).

The combination of an open building philosophy and DfD design principles provides a firm basis to design digitally fabricated systems for building renovation that are reusable. Some principles such as modularity and interchangeability are also MCC enablers but are generally considered only from a manufacturer's point of view. Partitioning and interior finishes are the most often replaced components over the life cycle of a building; however, the partitions are usually constructed with overly permanent constructive processes or ones that cannot be reused, either as a constructive system that maintains its functionality but in new combinations, or as materials that can be reused for other purposes (Durmisevic & Yeang, 2009).

Towards a Generic Grammar

A set of design principles can be derived from the reconciliation of MCC, DfD, and building renovation guidelines with the technical requirements of partition walls (Brandão, 2022). The first critical step in the design of partition wall systems for the outlined context is to recognize that these must be designed in terms of their interfaces with the remaining building systems. Interfaces in this context are understood as "a set of design parameters describing how two objects mutually interact" (Salvador, 2007: 225), which will include both the geometry of the connection and the physical or chemical exchanges.

In addition, instead of starting the design process from a *tabula rasa*, we must start by considering the constrained condition of an assembled wall in an existing building which might be disassembled for maintenance, upgrading, or reconfiguration of the space plan, ideally with minimal disruption for the inhabitants. Disassembly for maintenance might be required if other systems, such as services, are embedded in the wall. Upgrading might be driven by a desire to change finishes or improve some aspect of performance; while space plan changes might involve removing sections or all the existing walls (Brandão, 2022).

Each of the above disassembly actions is related with a different level of the technical decomposition of the wall system. Space plan changes are the limit case that might involve a complete removal of the system to a new location, and which implies removing every component through some door. Thus, the wall system will need to be subdivided into smaller components, whose dimensions are determined by their weight and the previously mentioned constraints, but also by material dimensions and transport considerations. Consequently, there will be internal interfaces between the system components, whose nature is contingent on the ease of disassembly and the degree of combinability with other systems components. Each component should be locally demountable without requiring the removal of other system components, to maximize the flexibility of the system to space plan adaptations. Hence, component-to-component internal interfaces should be bi-directionally reversible.

Conclusion

The above principles are generic, in the sense that no specific technical solutions are prescribed, and should be viewed as ideals to achieve. Hence, there is sufficient latitude for designers to interpret and adapt them to the specific circumstances of local contexts, design goals, closely available materials, and building practices. They should be used in conjunction with a holistic view of sustainable construction, since designing for component level disassembly and using digital fabrication might not be the most appropriate solutions in some contexts.

Designing digitally fabricated systems for component level reuse can increase the likelihood that systems, components, parts, and materials are used to the full extent of their technical life cycle. Sustainability requires local solutions to a common problem. Solutions will likely not be perfect and may have to be negotiated and iterated. A generic grammar offers a template that can be used to develop open building renovation systems for specific contexts.

Note

1. "The long tail" is the tail of the Pareto distribution of volume/product variants and refers to the low demand or low volume products that make up the bulk of a market product offerings. It also describes a strategy of keeping large inventories of low-sales volume products combined with a few large volume ones (Anderson, 2006).

Acknowledgements

Filipe Brandão's PhD research is funded by a Fundação para a Ciência e a Tecnologia (FCT) scholarship, reference 2020.08659.BD.

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