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CORK RE-WALL

Computational methods of automatic generation and digital fabrication of partition walls for building renovation

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ABSTRACT
Developments in computational design methods and their integration with digital fabrication processes enable us to envisage a mass customized fabrication paradigm. Such is particularly suited to building renovation, a diversified corpus in which interventions are surgical and unique, and where partition walls are the most frequently replaced components. The main objective is to develop a disassemble-able and customizable solution of partition walls, with natural and renewable materials, insulation cork board and wood, for the context of building renovation. To meet this end is necessary to develop the construction system, the generative process for digital design and fabrication and a graphical user interface for building owners to interact. This design-to-production system will generate drawings for fabrication, instructions for assembly, and cost estimation. We foresee that the adoption of a file-to-factory process will present several advantages in this context: maximizing efficiency and speed of the construction process without reducing scope or increasing cost, contributing to a more sustainable construction process.

INTRODUCTION

Advances in the integration of generative design systems and digital fabrication in architecture have lead a number of authors to speak of the emergence of a mass customized construction paradigm (Kolarevic, 2001, 2003, 2013, 2015; Kieran and Timberlake, 2003; Naboni and Paoletti, 2015). Mass Customization (MC) has been widely studied and adopted in manufacturing with the purpose of improving customer satisfaction by allowing the user to participate in the design of the product. It is a particularly fitting paradigm for the building construction industry, whose products are mostly prototypical in nature (Kieran and Timberlake, 2003). The applicability of mass customization at the scale of architecture has been demonstrated in mass housing (Duarte, 2005; Benros and Duarte, 2009) and recent work is aiming to do so in custom prefabricated housing (Khalili-Araghi and Kolarevic, 2016; Kwiecinski et al., 2016), either using BIM or shape grammars, and at the scale of the building component (Sass and Botha, 2006; Gramazio and Kohler, 2008).

While at the research level there has been significant developments in generative systems with the capacity to automate the design of buildings, a precondition for MC, applications of MC in practice have been limited to the choice of finishes in prefabricated housing (Kolarevic, 2015) or customization of materials and components by the supply side of the construction industry mostly aimed at architects. Though architects frequently act as proxies to clients, these may or may not be the customers / building owners or even its users. Also, in interior renovations, where partitions and interior finishes are the most frequently replaced components in the building lifetime (Crowther, 2009), the architect is often not involved. These works are frequently handled by small contractors, directly hired by the building owner, that use existing construction methods that do not cater for reuse or disassembly (Durmisevic and Yeang, 2009) and are less likely to use or benefit from high performance custom made solutions. Open Building philosophy proponents suggest a different path to MC, focusing on open standards of interfaces between building layers or components (Habraken, 2003; Nijs, Durmisevic and Halman, 2011). These goals are in fact complementary to the proponents of generative systems and digital fabrication, but as Habraken (2003) suggests, construction is both cultural and technical and to successfully change it, the solutions must involve all actors, architects, builders and users, and focus not on the longer lasting layers, such as the building structure, but on the fit-out systems.

Recent research has aimed to develop solutions for retrofitting building facades using integrated design-to-fabrication processes to provide high energy-efficient customized prefabricated building components (Veld, 2015; Mestre, Iten and Almeida, 2016; Barco et al., 2017) to building owners.

The aim of this research is to develop a disassemble-able and customizable solution of partition walls, with natural and renewable materials, insulation cork board and wood, for the context of building renovation, with a parametric model and graphical interface that allows users to co-design and digitally fabricate and assemble their walls.

We foresee that the adoption of a file-to-factory process will present several advantages in this context: maximizing efficiency and speed of the construction process without reducing scope or increasing cost, contributing to a more sustainable construction process and to socially more adaptable buildings.

In the following section, the context of the research will be briefly outlined. In Methodology, the proposed method for the PhD research will be described together with the research objectives.

Renovation

Building renovation as gained increasing importance in the Portuguese context, in a background of decreasing construction industry activity (INE, 2016). In a framework of housing surplus (Carvalho, 2013), with circumscribed exceptions, a tendency of increasing relevance of building renovation is foreseeable, bringing it closer to EU average (Freitas, 2012), where it represents more than half of the activity in the construction sector.

Building renovation design and construction are piecemeal by nature and as such not prone to standardized construction methods. While in buildings built with traditional construction methods the difficulty arises of the characteristics of the constructive system and the age added entropy, in modern buildings the main cause is the division into horizontal properties, which eliminates possible economies of scale. Other important aspects of the renovation work in these types of buildings is the need to intervene while the building is in use. Which further justifies the importance of light construction and disassembly methods that reduce inconveniences such as noise, dust and the removal of large quantities of debris.

The partitioning and the interior finishes are the most frequently replaced components in the building lifetime, nonetheless partitions, as other building components, are still frequently built with construction methods, such as ceramic hollow brick walls or galvanized steel frame partitions, that don't cater for reuse or disassembly (Durmisevic and Yeang, 2009). And while there is a growing awareness of the need to reduce the waste of materials and energy in the building's lifecycle, most efforts have concentrated on the construction or demotion processes and not on the reuse of materials or components (Crowther, 2009).

Previous research (Veld, 2015) as suggested that a path to overcome these issues is to change the renovation process to an off-site prefabrication process with the potential to reduce cost, waste, time and disturbances while at the same time increasing performance and quality. Further, moving the high-skill work from the site to the factory and leaving the only unskilled assembly work to be performed on-site may have several advantages to workers (Kieran and Timberlake, 2003) and to users (Habraken, 2003).

Digital Design and Fabrication

In this context, it is urgent to develop an efficient constructive system that adapts traditional materials and techniques to contemporary requirements and technologies. According to Stevens and Nelson (2015) it is necessary to understand the role of the new tools available to architects to integrate vernacular construction knowledge. Gramazio and Kohler (2008) state that materiality is being gradually augmented with digital features and is developed by its interaction with digital processes in design and construction. Digital workflow logics in architecture are beginning to change design and building processes effectively reorganizing the industry (Marble, 2012). Which is leading to new “material praxis” (Oxman and Oxman, 2010) and shifting the main role of the architect of mass customization systems to the design of metatypes (Kolarevic 2015). Fabian Scheurer (2014) points to Design-to-Production, File-to-Factory and Digital Crafting as important steps towards customized construction. The key lies in CAD parametric models where elements may be automatically generated and connected with CAD/CAM production processes, that reduce the cost of production of complex forms (Kieran and Timberlake, 2003).

The previously referred factors enable us to state that the integration of digital design and fabrication, in a file-to-factory logic, is prone to flexible and precise processes (Sousa, 2010). Architecture, a prototypical activity in which each building is designed for a client and tested on the construction site (Kieran and Timberlake, 2003), can now benefit of the advantages of mass production - precision, low cost, simulation and testing - combined with those of customization. According to Kolarevic (2015), the enabling technologies are available so the main challenge is the development of interfaces for customization. The Instant House (Sass and Botha, 2006; Cardoso and Sass, 2008) and the underlying Wood Frame Grammar (Sass, 2006) are paradigmatic examples of integration of generative processes with digital fabrication, however they only approach part of the construction problem, ignoring thermal and acoustic issues or the integration of infrastructural systems. The need to communicate the assembly or disassembly processes are not considered either. Other examples, such as Benros and Duarte (2009) or Kwiecinski et al (2016) have developed generative systems for existing construction systems, and Benros et al (2011) develops a generative system for a new construction system, yet none of them explicitly addresses the disassembly problem or is aimed at building owners.

METHODOLOGY

The main objective of the proposed research is to develop a disassemble-able and customizable construction system of partition walls, with natural and renewable materials, insulation cork board and wood, for the context of building renovation, implemented through a computational model for a generic user which generates drawings for digital fabrication and instructions for its assembly. This system, which we name Cork reWall, will be composed of a parametric model, a construction system and a graphical user interface.

From the research objective, the following investigation questions are derived:

1) State-of-the-Art: Which design-to-production systems exist?

1. To what extent do these systems respond to the specific research objective?
2. Which are the relevant criteria to be considered in the development of the proposed system?

2) Design / Prototype / Test: How can a design-to-production system of a wood and cork partition wall be designed for building renovation and disassembly, to be used by building owners?

1. How is the system assembled and disassembled?
2. How can it be digitally fabricated?
3. How should a design interface be so that it can be used by a generic user?
4. How should instructions be communicated to and end user, without previous construction experience, that would allow him to assemble a digitally generated construction system?

3) Test:

1. What limitations do users find in the system?
2. How does Cork reWall compare with existing partitions in standard tests?

4) Reflect:

1. What are the improvements and limitations of Cork reWall? (Conclusions)
2. How can the limitations be addressed? (Recommendations)

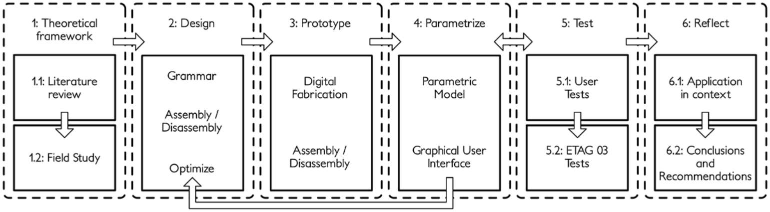

Figure 1: Research methodology (adapted from (Nijs, Durmisevic and Halman, 2011)).

Each group of questions will be addressed in its specific phase of the research, in the sequence outlined in figure 1, except for the second group which will be spread about Design, Prototype and Parametrize phases. The development of these phases will be performed in cycles, we foresee that at least 3 cycles are needed to develop the construction system and the parametric model.

In the first phase the theoretical framework will be outlined based on a literature review and a field study of building renovation. The literature review will focus on: how the paradigms of Mass Customization and Personal Fabrication have been adopted in architecture and construction; generative systems and their integration with graphical user interfaces; digital fabrication as a production tool of customizable components of construction systems; Open Building and Design for Disassembly as philosophies for more eco-efficient and flexible construction systems; properties and possibilities of personalization of Insulation Cork Board (ICB) and wood. The field study will focus on interviews with academics in the researched fields, architects, construction companies and users.

The literature review and the field study will allow to establish a set of design goals and criteria for the development of the design-to-production system. This development will occur over the second, the third and the fourth phases, each with its specific focus, iteratively along several cycles of designing, prototyping and parametrizing, including the feedback from the participating industry partners.

The first cycle of the Design phase will start with several candidate systems based on typical examples found in the literature or the field, progressing to a single solution.

In the first cycle, generic subdivision grammars of candidate construction systems will be developed for a simple wall, defining for each of them its components and the assembly / disassembly sequence. A maximum of two alternatives will be chosen for the next cycle, based on how they achieve the goals and criteria defined on the first phase. These alternatives will be redesigned based on the findings of the subsequent phases and the critiques of the industrial partners. In this cycle, the candidate systems will be developed to respond to further cases, such as baseboards, doors or corners. The final solution will have to respond to all the cases and have a viable assembly and disassembly sequence. These sequences will be digitally simulated, using 3D modelling software. Simulations will be also used to optimize static and acoustic behavior.

In the third phase, the alternatives will be prototyped to physically check viability, constraints, dimensioning and determine the specific problems of using the chosen materials with digital fabrication processes. They will also be assembled / disassembled using the sequence predefined at the design phase to determine its adequateness. At later cycles, the assembly will be performed in conditions that simulate the context of application, with the objective of finding unforeseen constraints and problems. Registering the fabrication and assembly steps, times and material and energy flows will allow to gather data for a life cycle study.

The fourth phase includes developing the parametric models for each of the candidate systems, determining what is customizable - the user design space, how does the user interact with the model, and the nature of the user inputs. We foresee that graphical interface is necessary at least to provide visual feedback of the generated results. Previous experience indicates that models of interface that mix selection and generation of options with user direct input are needed to allow the system to generate higher complex solution whilst maintaining the user required CAD knowledge low. The other outputs must include, drawings in appropriate format for digital fabrication, bills of materials, cost estimates and visual instructions for user assembly.

Having clarified the nature of inputs and outputs, the next step is to extract the design rules of the constructive system that meet the user design space and the rules of assembly to build the generative systems. The analytic systems (statics, acoustic, quantities, lifecycle) and the production system for digital fabrication will them be built.

The deliverable of these three previous phases is a working design-to-production system, comprising a constructive system, a parametric model and the prototype of the graphical user interface. The research will be conducted with the participation of a construction company, the largest manufacturer of ICB and a manufacturer of wood composites, respectively Grupo CASAIS, AMORIM ISOLAMENTOS and LAMINAR.

The aim of the fifth phase is to test the previously developed system from the user and technical viewpoint. User tests will be conducted in the context of workshop in which users unfamiliar with the system can interact with the model, generate solutions, digitally fabricate and assemble them, to determine:

1- Design of solutions: Clarity and usability of the generative system, capacity to produce viable solutions that meet the user requirements

2- Digital Fabrication: Adequateness of the generated files for digital fabrication.

3- Assembly: Ease of assembly of the system and clarity of the generated solutions.

The technical test will be based on the European Technical Assessment Guidelines (ETAG) 03 for partition walls and will be conducted in controlled setting at ITECONS laboratory. Acoustic tests not included in the ETAG will also be performed. The user feedback and the test reports will provide information for the research questions of this phase and for an overall revision of the system.

The last phase will allow the evaluation of the application of the system in the renovation of a building. A solution will be generated by the building owner / architect, digitally fabricated and assembled on-site. It will provide data about the functioning of the design and lead to a set of conclusions and recommendations.

EXPECTED RESULTS

The proposed PhD research aims to develop a complete design-to-production system of partition walls for building renovation, which comprises a constructive system with natural and renewable materials that is disassemble able, a parametric model that generates designs for production and instructions for assembly and a co-design interface for building owners, and which will be a step forward towards mass customization of building, contributing to a more sustainable construction process and to socially more adaptable buildings. It will further contribute to the extension of the literature on generative systems with methods of generation of assembly instructions for construction systems.

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