P. Janssen, P. Loh, A. Raonic, M. A. Schnabel (eds.), *Protocols, Flows and Glitches, Proceedings of the 22nd International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2017*, 251-261.

ENABLING CUSTOMER CHOICE IN HOUSING

Mass Customisation Solution for Prefabricated House Manufacturers

RENEE PUUSEPP[1], TAAVI LÕOKE[2] and KAIKO KIVI[3]
[1,2]*Estonian Academy of Arts, Estonian*
[1]*renee.puusepp@artun.ee* [2]*taavi.looke@gmail.com*
[3]*Creatomus Solutions, Estonian*
[3]*kaiko@creatomus.com*

Abstract. This paper presents a live and tested solution that enables home buyers to choose and customise their future homes in a web browser. It allows future owners and residents to configure and visualise their home in 3D but also keep it affordable by displaying the construction costs back to users in real-time. The proposed solution is analysed in the context of current housing market, excising web and BIM technologies and compared to currently available solutions. Additionally, we have been tracking visitor behaviour by using web analytics and can draw some conclusions about its performance.

Keywords. Mass customisation; housing; configurators; combinatorics; web technologies.

1. Introduction

With the invention of new web technologies in general and with the maturing of WebGL in particular it has become increasingly more feasible to build web applications that manipulate 3D geometry directly in web-browsers. This has created new opportunities for bridging the gap between buyer's needs to customise the design and efficient fabrication of new houses. The main value of this research lies not within the novelty of the subject area, but within the flexibility of the software architecture and suggested workflow as a generic solution for mass customising houses. We have established a scalable concept and direct workflow from desktop 3D modelling software via parametric software add-ons into a web-friendly format, allowing architects to present design options to the customer without the need of face-to-face consultation.

We have created a working online solution and have been tracking the use of our prototype solution using web analytics. Based on this we can draw some conclusions on the end-user behaviour. More specifically, we are interested in finding the right balance between the freedom of end-user's choice and the ease of navigating the landscape of choice.

Although product configurators have become a common online sales and marketing solution, mass customisation of houses is fairly different from the personalisation of other products and is not yet used by manufacturers. Kendall (2013) points out that while the car industry is moving towards mass customisation, it is not a suitable model for housing as houses are tied to a specific location while the automobiles are particularly 'placeless'. Westerholm (2013) stresses that car industries and shoe manufacturers have introduced advanced web configurators because these they are operating with big volumes and can afford to invest into web technologies. Construction industry has been lagging behind because almost each project is unique and connected to its surroundings and cultural context. To date, there has not been a widely accepted workflow and software that makes mass customisation of houses possible.

We believe that our solution - although still in its early stage - can achieve scalability by giving individual architects the means to build online configurators. Empowered with appropriate tools architects will be able to offer automated choice for customers. The consequent shift in consultation and decision making process would epitomise the transformation of their role from being the designer of outputs (houses) towards being the designer of systems. Such kind of a transformation can be described both from the biologist's and the software engineer's perspective distinguishing between the creator of the "usable artefact" or phenotype and "the editable source code" or genotype (Fuller & Haque 2008). The paper argues that with the rise of prefabrication and mass customisation, customers will be given ability to configure suitable design solutions and architects simply need to provide the operational guidelines and content to enable it.

Already in 1980s Bernard Cache ja Gilles Deleuze suggested a distinction between 'object' and 'objectile' (Carpo 2011) in order to separate the mechanism of creation from the output. The objectile as opposed to an object, is an algorithm, which may determine an infinite variety of different objects. While this distinction makes a perfect sense in todays paradigm of parametricism, back then it remained an abstract concept without a concrete technical implementation. We find this distinction especially appropriate in order to describe the difference between a configurator and a configuration in the quest for defining mass customisation in prefabricated housing.

2. Demand for Mass Customisation in Housing

"The term mass customisation denotes an offering that meets the demands of each individual customer, whilst still being produced with mass production efficiency." (Piroozfar & Piller 2013)

Mass-customisation of houses can be seen as a blend of two strategies - mass production and individual customisation. While the latter is an age-old phenomenon, mass production can be attributed to the 20th century. More specifically, mass production strategies were invented after the Second World War in order to rebuild societies and relieve housing shortages when existing construction methods could not meet the societal demands any more (Thuesen et al. 2013). While the mainstream construction industry in 1950s and 1960s aligned itself with the mass production and gradually become more streamlined in order to follow tight production and construction schedules, the early concept of mass customisation was also introduced to the public at the same time. In early 1960s Habraken (1972) proposed an alternative solution to the modernist mass housing that comprised of 'support' or a base building and 'infill' - a customisable fit-out.

In reality, mass customisation of houses has only recently started becoming a feasible construction method. While there has been a number conceptual works experimenting with the idea, the first real projects combining personalisation at the industrial scale and with industrial efficiency are surprisingly recent. This is perhaps not so much to do with technical possibilities, but can be largely attributed to the demand and market dynamics in general. For example, the current housing market in the Netherlands - the country that is undoubtedly one of the forerunners in adopting mass customisation in housing - is shifting towards a demand market instead of the supply market, as Dalhuisen (Zeist 2014) points out.

Housing trends in the Netherlands started pointing towards mass customisation in 1990s when some well-known examples of participatory design were brought into existence. While schemes like Borneo Sporenburg by West 8 in Amsterdam (Evans 2008) are not strictly speaking mass customisation examples, they have certainly paved the way to ones that have followed. In recent decades there have been a number of residential developments that are loosely adopting the concept of mass customisation as a marketing, design and construction strategy. One of the largest ones is Homeruskwartier in Almere, others include Palet van Delft, Wenswonen, Fenixlofts and many other smaller developments.

According to Oey (Zeist 2014) one of the reasons why mass customisation of housing is so popular in the Netherlands is because lot of Dutch people likes to build their own house which in turn has led to so called self-building movement. Same but perhaps more recent trends can be observed in the United Kingdom, where there is somewhat of a revolution undergoing in the housing sector in these years. Self and custom build is hoped to contribute towards solving the national housing crisis that has been ever deepening after mass production of modernist housing in 1970s. Similarly to Dutch people, a majority of home buyers in the UK are dreaming of building their own home. The Building Societies Association's survey (2012) found outr that "over half of all respondents (53%) said they would be interested in building their own home".

As a response, a number of new self and custom build developments have been granted planning permissions - the Heartlands regeneration scheme in Cornwall, Park Prewett development in Basingstoke and Beechwood West in Basildon, to name just a few. All of these feature a strong mass customisation element - future residents are given a choice to customize their home within the limits permitted by the architects, developers, local planners and house manufacturers. In fact, most of permissible house types are manufactured off-site which is also seen as a key measure to relieve the ongoing housing crisis in the UK.

There is a clear gap in the market that should be filled with an affordable technology that connects customisation experience of the home buyer with the efficiency of off-site manufacturing into a seamless workflow. We shall refer to such a technology as house configurators. House configurators are 'objectiles' in deleuzian language. House configurators produce unique 'objects' or houses for the long tail of home buyers who don't like to live in a mainstream mass-produced home. Paraphrasing Anderson (2006) house configurators are tools for the future of business that allow selling less of more - they are aggregators of low demand products that collectively build a better market share than the best selling but un-customised houses

3. Online House Configurators

Web-based mass customisation technologies for housing have been researched and tested before. Some earlier examples include an interactive system for the design of customised housing by Duarte & Eloy (2000); Huang & Krawczyk (2006a, 2006b) and Huang alone (2007) have proposed a web-based questionnaire and a system to configure prefabricated houses. Typically, such attempts have stayed at the conceptual level and have achieved very little if any adoption by the industry.

In contrast to the aforementioned attempts YIT Stylemachine created by 3D Render (Westerholm 2013) has been actually used by the renown Finnish construction company. Stylemachine presents the end user an opportunity to customise generic rooms (e.g. kitchen, living room, bedrooms) with a set of predefined choices. Users can configure individual rooms but not the overall layout of the apartment. As the application is based on a set of pre-rendered images and image components, high visual quality gets preference over navigation and overall configurability. Similar applications to Stylemachine are in use in the Netherlands; Woonmodule and Palet van Delft (Zeist 2014) to just name few of these.

While there is clearly a 3D model or a set of models needed for creating such applications, they typically feature no real-time interaction between the user and the model. All choices offered to end-users are modeled in advance, in most cases also rendered and then uploaded for the user to browse.

However, recently a new type of building configurators has surfaced. In such configurators the user is actually interacting with 3D model guided by some quantitative information retrieved from the model in real time. For example, Studio Shed's Configurator (2016) is a good example where design customisation aligns with the production efficiency. Similarly to many online car configurators, this web solution is one-off configurator where the building (shed) model is tightly coupled with the customisation mechanism and the user interface of the system. In this respect Woonconnect (Sengers 2016) seems to be a more scalable solution. It is built on top of a digital library of building components provided by over a hundred different manufacturers. These components can be integrated with building applications and thus Woonconnect allows users to create new house designs.

4. A New Kid on the Block

The following sections in this paper describe a new online house configurator (figure 1) technology. We give an overview of its technical architecture, explain the theoretical framework for the customer choice model and draw some early conclusions based on web analytics of the first 6 months after the launch in spring 2016.

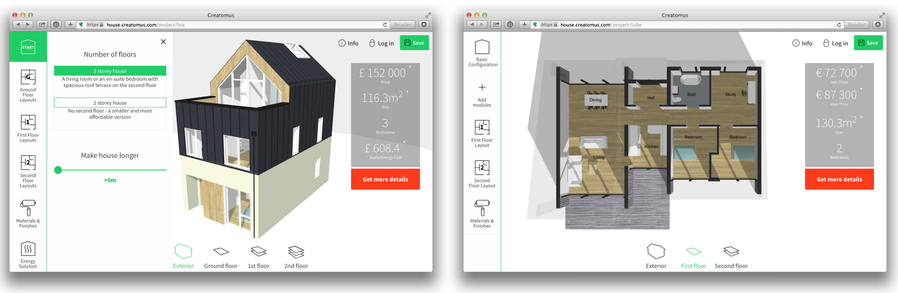

Figure 1. Screen captures of Creatomus' house configurator on https://house.creatomus.com/project/hta and https://house.creatomus.com/project/tube.

The house configurator technology was initially invented for enabling mass customisation of prefabricated private houses, but it can be adapted for other building typologies as well. The configurator is a web-based application that is intended to be easy and fun to use, yet guide home buyers through the decision making process of getting the house that they need and can afford to buy. It allows future owners to explore and configure the house in 3D while keeping an eye on the construction costs. While all design decisions are displayed in the interactive 3D model, the cost of each decision is immediately reflected in the total price for the selected design. Once the potential buyer is happy with the configuration, they can save the design for further communication with the manufacturer and the architect.

Home buyers are given the flexibility to customise general size and geometrical parameters (e.g. the size of windows, the pitch of the roof etc.) and layout options within the chosen house type. They can also explore different material variations and swap building products with alternatives ones. The design of a configurable house in general and all given design choices are conceptually organised into decision graphs. A simple decision graph would have a few plan layout options at each floor level and perhaps a couple of exterior finishes options leading to basic yet clearly presented choice model. More complex decision graphs can lead to a large number of different house configurations that are virtually impossible to reproduce using conventional CAD applications.

At the background, the application is connected to a web service that assembles 3D models by combining together elements designed by architects. 3D mesh geometry is manipulated in real time; the price of the house is also associated with the model geometry (e.g. floor area) and calculated near real-time. All design choices offered to the buyer are predefined but the final design is a result of combinatorics carried out according to the choice made by the buyer and as such is not predetermined. The modelling of designs choices is carried out in a CAD application (Rhinoceros), but the decision graph is knitted together online in a content management system. This separation of tools is yet another measure of increasing the flexibility and scalability of the system - new choices can be created and added dynamically and previously created choices can recombined in order to assemble new configurable models.

5. Definition of the Configurable Model

A configurable model can be conceptually defined as a function or an algorithm that allows the user to change some given parameters. When the buyer's decisions are added to the configurable model, then the result is a defined architectural object or the configuration. The configurable model comprises all versions that the client can create by making different decisions. Principally the configurator and the configuration relate the same way as object and objectile as described by Bernard Cache (Carpo 2011): the configurator *objectile is an algorithm that can create several different outcomes; the configuration* object is one of the possible outcomes. Every configuration choice is comprised of options that the user can choose from. Presently, we have defined three types of choices on the basis of how they affect the architectural object:

- Choices of spatial alternatives offer different solutions in terms of floor layouts, number of floors, shape of the roof, etc.
- Choices of spatial transformations offer the user a way to manipulate the geometry by changing its geometrical parameters. Generally it can be used for changing the length and width of the house, the height of the ceiling, the pitch of the roof, etc.
- Choices of construction/product/finishing allow the selection of different materials, structural systems and building products. Generally these mean changes in construction but do not change the geometry of the house. The selection could for example involve exterior wall finishing, window types or other building materials (e.g. solar panels).

The decision graph architecture (figure 2) always has the root option of the model - a part that is visible to the user from the beginning. It is the starting point of the decision graph that has a reference to all first-level choices. In complex configurators, every option in a choice can have two types of information added:

- Sub-choices are choices that become unlocked once the user has made a decision for the parent option. This allows more complex decision graph of the configurator and offers a wider range of choices in a logical order.
- Semantic information - machine-readable information about the given choice, allowing the configurator to display numeric or other type of data; e.g. construction parameters, energy efficiency and price calculations. In the web interface this information can be extracted for all chosen model options in order to inform decision-making by summing up values for the bill of quantities or calculating energy efficiency based on the building geometry.

The critical question when implementing the decision graph architecture is to choose the most appropriate modelling paradigm. As mesh geometry does not contain semantic information, it is much easier to create choices: every object can be handled as an independent model and the simple action of pulling these models together leads to the final configuration. This would be far more complicated with BIM models since manipulating the model geometry the interdependencies between different model elements would also need to be manipulated. On the other hand, if this problem was successfully solved, BIM would be a better option because the BIM-based models can be immediately used in the following design process.

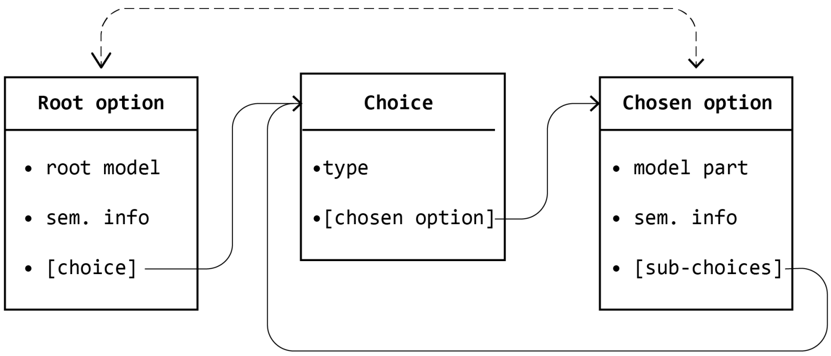

Figure 2. The decision graph architecture.

Nevertheless, our choice was to use mesh models. One of the main arguments is very pragmatic - spatial transformation choices are technically hard to implement in the currently available online BIM viewers (e.g. in Bimsync or Autodesk Forge Viewer) that do not support advanced manipulation of element geometries. Another reason is that users do not need to see and configure the entire BIM data. Therefore, it is technically more feasible to define partial models with relevant semantic metadata and deliver optimised 3D mesh representation to the web client. Mesh geometry can be created from almost any 3D representation of buildings and is thus a more universal medium. Plain mesh will have no parametric restrictions and rendering complexity like BIM element classes. Added technical and semantic descriptions and 3D rendering properties can be designed specifically for the configurator. Technical properties of partial models such as cost, heat loss or gain, number of bedrooms etc. that can be summarised and displayed as total figures for the chosen configuration. The downside of this approach is that the configurator will produce information for the web viewer only. Such a representation is not reusable in the further design process. This problem can be addressed with a separate backend tool that lets the architect or a backend service assemble the configuration in a desktop software format together with original CAD or BIM details (see section 7).

6. Learning from Users

One of the advantages for house manufacturers of using house configurators is the possibility of supporting product design, marketing and sales decisions on observable and quantifiable user behavior. Modern web analytics technology makes it feasible to significantly shorten the customer feedback cycle. In our case, the analysis of web visitors' behavior becomes an important driver in designing the house configurator's decision graph. It is not only possible to observe an individual visitor's actions but also draw conclusions on the overall performance of design elements and identify popular design choices based on aggregated metrics.

We have carried out both qualitative and quantitative tests using our live house configurators. As our primary aim has not been to analyse any particular decision graph of configurator but the overall performance of the concept, all conclusions presented in this paper have been generalised. Qualitative usability test were carried out with a handful of users of which some were actually looking to buy a new house or were just recently done so, and a few casual web users. Quantitative tests were carried out with 133 people.

The interface of online house configurators was proven fairly intuitive and user friendly. Users managed to explore different views of the model and different design options easily. We found out that home buyers are indeed ready to focus on the task and even expect to concentrate because they are making important decisions about their future. It was found out that potential home buyers can handle 3D navigation such as rotating and zooming fairly well. While professional users (e.g. architects) are naturally more likely to navigate the 3D model by mouse, our initial doubts that people would not know how to explore 3D space were not grounded. Simple 3D navigation seems to be well within the capacity of a common web user.

One of the difficulties in using the configurator was finding a suitable camera angle for making certain design choices. Some users tend to click on design options that they cannot see - e.g. clicking on floor plan layout options when they are looking at the exterior view. Many users also failed to notice the total cost change when a new choice was selected. What seemed to take the longest time when using the configurator was understanding the difference between different design choices as presented in the configurator. Also, the real-time geometry changes in the 3D model were not always apparent - interaction with the interface that is detached from the 3D model seemed to be the culprit. It is suggested that choices should be somehow offered directly within the 3D model.

From the survey that was conducted after the quantitative test, we received some negative feedback about the clarity of graphics. However, it seems that the image quality was not an issue - even if everyone is used to high quality renderings, interactivity with the 3D models seems to compensate for the lower image quality. The biggest shortcoming of our current configurators is probably the number of design choices offered. Most of people get quickly used to the interface, but they also get quickly bored, if there is not enough choice offered.

7. Discussion: Beyond Simple Configuration

Zeist (2014) proposes a 5-stage process for mass customising houses in order to achieve truly personalised designs and form a user-centered design loop. This process includes the following stages: activity listing, activity descriptions, relationship diagrams, initial floor plan and final design. We offer a simpler workflow for involving clients into the design process. It comprises four stages:

1. An architect creates a configurable model using plug-ins in BIM/CAD software: options and chosen options with corresponding geometries and price calculations.
2. The model is uploaded to the web, ideally this stage would be automatic and only needs one click.
3. The client can access the configurator on the web and can make changes based on the options given by the architect and can get automatic live feedback about the geometry of the design, energy efficiency and price calculations.
4. When confirmed, the client's choices and comments are sent to the architect. The architect can access this data using a plugin, download them and recreate the configured model in the preferred design software.

This process should be cyclical: an architect creates a model, makes it accessible for the client and receives the client's choices and feedback. The workflow starts and ends with the architect and this gives the option to observe the stages in two groups: the 1st and the 3rd involves one of the parties (the architect or the client) either designing the model or making choices. The 2nd and 4th stage involve translating and forwarding data. The effectiveness of the workflow increases when the 1st and the 3rd step are handled in a single software platform. On the architect's side the model should be configured in the same BIM/CAD software that is used in their everyday design work. This functionality can be offered with plug-in software. On the client's side it should be a browser solution with no software downloads and installation.

When a configurable model is linked to the designing software in this way, it is fairly easy to use it as part of the design process in order to take narrative steps in designing and making relevant choices. Thereat the workflow is adjustable with many different user-scenarios. On one extreme it can be used for configuring finished designs that have many details and options. This could be applied for prefabricated houses that have been designed once and can be used over and over again; the user can choose among the solutions offered by the architect.

On the other extreme it can be used for fast communication between the architect and client in a standard design process: the architect creates a model that can be configured with a few choices, makes it available for the client, the client makes choices and the architect can add more detailed choices. This circle can be repeated as soon as new options become available. In addition these two workflows can be combined with each other. For example the user can choose a specific configuration from the reusable configurator and ask the architect to adjust it to the suit some specific needs.

References

"Lending information for self build in the UK" : 2012. Available from Building Societies Association<https://www.bsa.org.uk> (accessed 23.12.2016).

"Studio Shed Configurator" : 2016. Available from <https://www.studio-shed.com/configurator/> (accessed 23.12.2016).

Anderson, C.: 2006, *The Long Tail: Why the Future of Business is Selling Less of More*, Hyperion.

Carpo, M.: 2011, *The Alphabet and the Algorithm*, The MIT Press, Cambridge, Massachusetts.

Duarte, J.P. and Eloy, S.: 2000, A Web-based Interactive System for the Design of Customized Housing, *Decision-making in Urban and Civil Engineering*.

Evans, R.: 2008, *Urban Design Compendium 2: Delivering Quality Places*, English Partnerships, The Housing Corporation.

Fuller, M. and Haque, U.: 2008, *Situated Technologies Pamphlets 2: Urban Versioning System 1.0*, The Architectural League, New York.

Habraken, J.: 1972, *Supports: An Alternative to Mass Housing*, The Architectural Press, London.

Huang, C.H.: 2007, Virtual Architect, Questionnaire Approach of Programming Modular Houses, *Proceedings of the 11th Iberoamerican Congress of Digital Graphics*, 310-314.

Huang, C.H. and Krawczyk, R.J.: 2006a, Integrating Mass Customization With Prefabricated Housing, *Re-Thinking the Discourse: The Second International Conference of the Arab Society for Computer Aided Architectural Design*.

Huang, C.H. and Krawczyk, R.J.: 2006b, i_Prefab Home - Customizing Prefabricated Houses by Internet-Aided Design, *Communicating Space(s), 24th eCAADe Conference*, 690-698.

Kendall, S. 2013, The next wave in housing personalisation: customised residential fit-out, *in* P. Piroozfar and F. Piller (eds.), *Mass Customisation and Personalisation in Architecture and Construction*, Routledge, 42-52.

Piroozfar, P. and Piller, F. 2013, Mass customisation and personalisation in architecture and construction: an introduction, *in* P. Piroozfar and F. Piller (eds.), *Mass Customisation and Personalisation in Architecture and Construction*, Routledge, New York, 3-13.

Sengers, F.: 2016, "Smart-Eco Cities in the Netherlands: Trends and City Profiles 2016" . Available from <www.smart-eco-cities.org> (accessed 23.12.2016).

Westerholm, T. 2013, Stylemachine - case study: mass tailoring the housing block apartments on the internet, *in* P. Piroozfar and F. Piller (eds.), *Mass Customisation and Personalisation in Architecture and Construction*, Routledge, New York, 197-207.

Zeist, F.V.: 2014, *A bottom-up redevelopment strategy of (structurally) vacant office space in mass-customized housing solutions utilizing digital fabrication techniques*, Ph.D. Thesis, TU Delft.