System for customer participation in the design process of mass-customized houses

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The paper presents an undergoing research that aims at developing a system, which will allow customer participation in a design of mass-customized houses. The system will allow customers to self-configure a house in a preferred way in relation to the site where it is going to be constructed and with a respect to the prescribed architectural rules. Introducing customer participation in the design process of mass-customized houses allows users to find out individual design goals transforming the design process from being ill-defined into goal-oriented. The proposed system for customer participation could become feasible alternative to the traditional process of provisioning affordable houses improving the living quality in these market areas where architectural knowledge is unaffordable and missing.

Keywords: *Housing delivery process, mass customization, customer participation*

INTRODUCTION

Housing architecture as a design discipline, shaping human habitation, traditionally emerges as a result of close almost intimate cooperation of architect and client. Starting from the Renaissance time, when the housing architecture emancipated and a convenient life became appreciated, architecture of human habitation began to be designed in a manner dependent on the wishes of the owner (Słyk 2012). Moreover, the invention of perspective drawing allowed to present, evaluate and modify the design at the initial stage in order to meet customers' needs. Until the 19th century, houses were designed individually in an iterative process fulfilling all demands of the clients. The beginning of the 20th century brought an increase in urbanization and industrialization which both had an important impact on the design process.

From the 1920s, architects tried to apply mass production ideas to solve the housing problems. The Törten housing development by Walter Gropius, Le Corbusier's Domino Houses at Pessac or Frank Lloyd Wright's Usonian houses are examples of the designs of affordable mass housing, which are using industrialization to lower the building costs (Duarte 2005). Repercussions of those ideas are still visible today. The evolution of housing architecture, influenced by mass production, resulted in the development of design processes, in which the end user has minor influence on the design of the space he is purchasing and will be living in.

The emergence of the society of knowledge, composed of prosumers can relink housing architecture to real inhabitants expectations. In order to incorporate customers' needs in a design process of mass housing new selling strategies have to be implemented. One of such strategies, gaining nowadays a lot of popularity in consumer goods market, is mass-customization, which allows to individually customize products before they are industrially produced. In order to adopt mass-customization strategy in housing, traditional design processes have to evolve allowing customer participation on a massive scale. With help may come development of new computer systems allowing consumers to participate in the design of their houses without individual support of the architect, just by fulfilling prescribed architectural rules.

BACKGROUND

Design systems in housing

From decades architects have been inventing design rules used in their practice. These rules are based on architects' professional knowledge and experience. Unfortunately most of them passed away together with their creators. Hersey (1992) noticed that the idea that a recipe or algorithm can generate plans, facades, and designs for entire buildings goes back at least to the Roman architectural writer Vitruvius. According to Słyk (2012) algorithmic methodology existed in intellectual sphere ready to be effectively consumed by the computer. It had to be just transformed into computer language. Automatic generation of houses started to be explored in the architectural field already in the 70's with the advances in the computer science and emerging opportunities in computation.

Early works in that field tried to prove that it is possible to generate designs in certain historical style. The first attempts of automation of the design process were shape grammars invented by Stiny and Gips (1971), which were later on utilized to describe and analyse the style of Palladio (Stiny and Mitchell 1978). The idea of shape grammars explaining the style of Palladian villas was further developed by Hersey and Freedman (1992), who developed software called Possible Palladian Villas: The Program, which generated not only building plans but also facades in relation to it. Therefore it was proved that it is possible to automatically generate designs in certain historical style and gave a base for developing computer systems for newly invented architectural designs.

Idea of developing computer system for generating architectural designs was further developed by Duarte (2001, 2005) who proved that it is possible to encode together with architect his design rules and translate them into computer program that eventually would allow generating designs in his style. Description grammars and shape grammars were utilized for encoding intuitive set of rules of Alvaro Siza's design system for patio houses at Malagueira. Integrated System developed by Benros and Duarte (2009) permitted mass production of customized housing based on Kingspan's building system. For this purpose the ABC design system, invented by the Spanish architect Manuel Gausa, was encoded into the computer program with a use of parametric design. The system was designed to assist architects in the conception of dwellings and in the production of the corresponding construction documents but it also produced the framework for the mass customization of housing.

Research of Merrell, Schkufza and Koltun (2010) showed that it is technically possible to develop software that would not only automate generation of new houses but could partly learn from architect's works. Implemented method analyses architectural programs from catalogues of residential layouts and utilizes collected information to generate new architectural layouts in relation to desirable house requirements. Moreover, the external appearance of the buildings emerges out of generated layouts, and can be customized in a variety of decorative styles specified in a template, listing the geometric and material properties of every building element. This building layout procedure was invented for the purpose of computer graphics applications and therefore it was idealized and does not take into account the myriad of site-specific and client-specific factors that are considered by architects. In a real world architectural practice, house design processes are also affected by the conditions related to the specific plot where the building is going to be placed and client's personality and his individual needs.

Collected examples showed that inventing design rules and employing them in architectural practice is rooted in architectural design tradition. Nowadays architects supported by computer design systems can encode their design rules both to explicitly record them and automatically generate possible outcomes. Such techniques might allow customer participation in the design process of mass-customized houses but invented systems have to be designed allowing for high level of customization of the designs both by the users and in relation to the chosen site localization.

Problem statement

The majority of single family houses build in Poland are not individually designed by architects, but are built based on the documentation from the catalogues of typical houses. Such architecture gained popularity, mostly due to low prices of purchase, despite the fact that often they do not suit local conditions of the plot or needs of future inhabitants. Although evolution of pattern books into Internet web services with build-in advanced search tools can speed up the process of browsing through design proposals, it does not guarantee user satisfaction connected with finding desired design. To meet users' needs such websites are increasing number of available search criteria at the same time massively developing various design solutions to cover all the possible solutions with predesigned alternatives. However those predesigned houses do not respond to specific site conditions related with the plot where they are going to be constructed and they offer small level of flexibility for accommodating different users' needs. Therefore the main motivation for this research is to investigate alternative method to offer customers affordable house designs, which would be better adapted to their preferences and different site conditions. Such alternative can be found in creating mass customization system that would allow customers to personalize their house in relation to the site where it is going to be constructed.

METHODOLOGY

Conceptual framework

In order to offer designs that are adapted to the preferences of customers, they have to be involved in the design process (Niemeijer et al. 2010). To achieve the goal of customer participation in the design process of mass-customized houses in relation to site conditions, the system must accommodate two sources of input information: customers' requirements and information about chosen site prescribed in national GIS databases. Design of single-family house is a complex task, which may be approached in many different ways depending on the typology of the house, user profile, localization of the site, and specific architectural design strategies. Therefore based on collected initial information system should be able to provide different house types that could be later on customized. Different mass-customized house types should be developed independently based on individual architect's design ideas. Additionally every house type should be supplemented with evaluation procedures that could help customers make further customization of every house typology. Those evaluation processes would allow customers to learn about architectural values of the customized house, optimize the design for its performance and verify its cost with estimated investment budget. Finally, the system should be able to generate building documentation prepared for manufacturing and assembly of the customized house.

This research is focused on investigating customer participation in one chosen building typology. For that purpose, one of the most popular typologies of an affordable, single-family houses built in Poland was chosen. Those types of houses are characterized by being one or two storey buildings, preferably with gable roof, which corresponds to Polish rough climate conditions and with integrated garage for either one or two cars. Hence the design system was

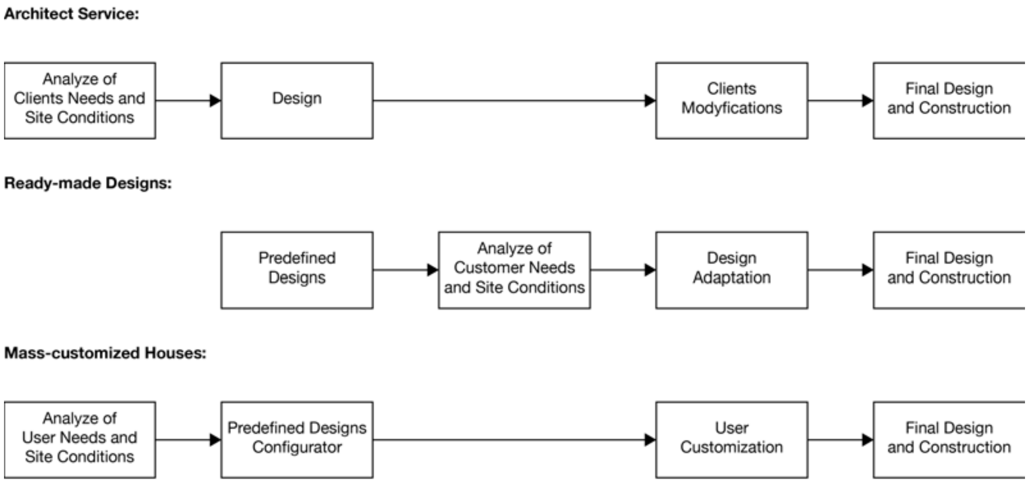

Figure 1
Existing models and proposed model

created in a way that it produces competitive outcomes, meeting similar esthetical expectations, but at the same time improving adjustment of the design to meet site conditions and individual user requirements.

Existing models and proposed model

Currently customers who wish to purchase building documentation of a house face a dilemma whether to have it designed by the architect or buy ready-made construction documentation (refer to figure 1). Traditional process of acquisition of a house design by direct cooperation with the architect is based on the thorough analysis of user's needs and specific site conditions. Such an analysis is a starting point to provide design proposal, which is later on iteratively being modified to fit users expectations. On the other hand this process is time consuming and it is hard to predict the final outcome at the beginning. Moreover, cost of architect's service is much higher then the cost of ready-made documentation, therefore majority of single family houses built in Poland are constructed basing on a ready-made documentation.

The ready-made documentation, despite being a compromise on the needs of investors, is chosen by many because of its price and possibility to see the visualizations and documentation at hand. Such method besides being relatively cheap is being frequently chosen because it allows seeing the product before it is being sold. To meet different users' needs publishers are developing various designs to cover all the possible solutions with predesigned alternatives. As a result customers find it difficult to choose the "perfect" house from numerous of types presented in catalogues. They quickly tend to get lost in the vast amount of possibilities and find it difficult to choose the solution that would fit all their needs. Therefore such process is often very time-consuming and at the same time does not guarantee success. Moreover, process of searching does not allow confronting designs with the plot where the building is going to be built and verify if it responds to local conditions. Therefore buyers of such documentation frequently realize that they want to adapt chosen design to the specific site conditions and to have it redesigned when the building is being placed on the actual site plan. However, such houses are typically designed in a way which is not intended to be easily customized, therefore even small changes in the layout of the building usually require to have the whole building redrawn.

Advanced digital technologies create third possibility to obtain building documentation. Introducing mass customization strategy through online tools could not only respond to the need of purchasing a house construction documentation at low price, but also to a series of needs currently being satisfied only by the individual projects: the ability to customize home design to the land and to the individual preferences. Based on the collected information introduced by the customer, the system could propose few different building typologies ready for further customization. By modifying the house design without direct support of the architect, but only through following built-in design principles, users could fulfil their needs in relation to the proposed house, as well as the need for self-creation.

SYSTEM PROTOTYPE

System flow

According to Benros and Duarte (2009) integrated system should combine a design system, a building system and a computer system. The design system encodes the rules for generating customized designs and a building system specifies how to produce them. Integration of this two systems is achieved by a computer system which is a software that enables the easy exploration and visualization of solutions, and automatically generates the information required for production using computer aided design and manufacturing. Therefore in order to create system that would allow for customer participation in the design process of mass-customized houses the design system for chosen housing typology had to be invented first. The invented system is focused on customer participation, therefore design process is initiated by customer who is indicating location of his plot and functional program of the building. Information provided by the customer is analysed and initial house design and its location on the plot are proposed. The configuration tools provide functionality to further customize the initial house design. User has the ability to customize his house, from adding or removing types of rooms, changing their size and location, choosing pieces of equipment and furniture and finally changing the external appearance of the building and the materials from which it is built. At every stage of setting up the house customer receives information on the indicative cost of its construction, which helps to stay in line with budget limitations. The developed system allows for flexible distribution of the functional program of the house, in relation to the external conditions and users preferences. The invented rules for positioning of the building on the site together with the rules for generating floor plans were supplemented with the rules for generating building facade. All of these rules maintain certain level of interaction allowing users to customize many elements of the building. This resulted in a complex system with many interdependent rules, which were grouped into three software modules responsible for different parts of the project: Site Planner, Home Planner and Facade Creator. All three modules are interdependent and they exchange information between each other. Information from all modules is intended to be collected in a Building Information Model, which allows not only for exploration and visualization of the design, but also to accelerate the creation of construction drawings and specifications.

Site Planner

In Site Planner user starts participation in the design process by indicating location of the plot where the building is going to be constructed. Site Planner collects from national GIS database information about chosen plot and analyses its special features: alignment to the cardinal directions of the world, position of the access route and main entrance and urban parameters prescribed in the master plan. At this step user also defines the initial home functional program, chooses the size of the garage and defines the ridge orientation of the building. This information allow

Figure 2
Functional modules representing different rooms in the building

Site Planner to estimate the initial dimensions of the building, set plot development area and propose optimal arrangement of the house on the plot. Building is located in order to maximize indoor sunlight and to create south facing outdoors, while the garage is located to minimize its shading area on the site and to minimize access path to the building. As a result Site Planner determines building position on the plot, location of major entries and exact location of the main building axis. This information is transferred to the Home Planner where it is used for detailed distribution of functional program, while Site Planer is constantly used in the background to verify the size of the house, its position in the development area and its correspondence to the master plan regulations.

Home Planner

In Home Planner user can customize in detail the design of his house. The configuration tools allow modifying spatial distribution of home functional program. Size and location of every module representing different rooms can be changed and all the modules can be added or removed. All the modules are based on modular grid (Figure 2) of 60 by 60 cm and have the same depth, which allows connecting them together and flexibly reconfiguring. Type of this connection is pre-set for every module separately and it could be either in a form of direct access, such as a door, or an open wall or there could be no connection when modules are separated by wall. Every module reacts responsively to its surroundings. Figure 3 presents possible adjacent connections for the module of kitchen.

Home planner creates a framework for customers to participate in the design process of house layout, which due to various customers' needs is an ill-defined problem. Therefore in order to provide customers with the designs that fulfil their needs, they are invited to participate in the design process where they can individually verify their expectations with provided capabilities. This participation process should be finalized with a complete planar layout of the spaces on each floor determining position of all the rooms and their surroundings. In order to guide users through this process optimization goals and intermediate task are being set. Spatial distribution of functional modules takes place in relation to the external and internal context. For this purpose the orientation to the World coordinates (which affect indoor sunlight) and the privacy gradient (which suggests placing common areas, such as the living room, closer to the entrance, while private spaces, such as bedrooms farther away) are used. Moreover, Home Planner uses few optimization technics, which allow

Figure 3
Possible adjacent connections for the kitchen module

for creating more rational floor plans. Optimization is focused on diminishing the number of installation shafts and for creating compact circulation scheme. When a planar layout of the spaces on each floor is completed, building layout is further developed by adding more details. Home Planner is adding major entries to the building, which are placed at the ends of the circulation scheme axes and transferred to the Facade Creator for customization of the facade.

Facade Creator

Facade Creator allows user to individually compose the facades of the house in relation to its roof pitch. User starts by placing building entries on the facade in the exact position taken from the Home Planner. These entries become then guiding facade openings to which corners' guidelines are added. These guidelines are used to generate possible localization of additional facade openings from which the user can choose the secondary facade openings based on his preferences. Chosen facade openings become guiding facade openings and the whole process starts from the beginning. Based on the invented set of rules Facade Creator is able to create asymmetrical although internally consistent composition of the facade. At the last stage user can choose the finishing materials from the predefined sets.

At the end of this process location of the entire facade opening is transferred back to the Home Planner and marked on the floor plan layout. All that information is collected in parametric Building Information Model, which allows for exploration and visualization of the design, evaluation of the building for its energy and environmental performance and estimation of the final building cost.

CONCLUSION

The proposed system for customer participation in the design process of mass-customized houses could become feasible alternative to the traditional process of provisioning affordable houses based on ready-made documentation. The invented design system was tested for possibility of designing small houses as well as middle-sized houses (Figure 4). The first four examples from the left present houses with identical functional program with approximately 100 square meters of living area and with a garage for one car. The last four examples illustrate the same principles but for the middle-sized house with approximately 145 square meters and a garage for two cars.

Invented system may give a solution for upgrading living conditions, site adaptation and architectural quality of widely popular catalogue houses. Development of such system may improve the living quality in these market areas where architectural knowledge is unaffordable, omitted and simply missing. Introducing customer participation in the design process of mass-customized houses allows users to find out individual design goals transforming the design process from being ill-defined into goal-oriented. Therefore allowing people to influence the design themselves can improve level of their satisfac-

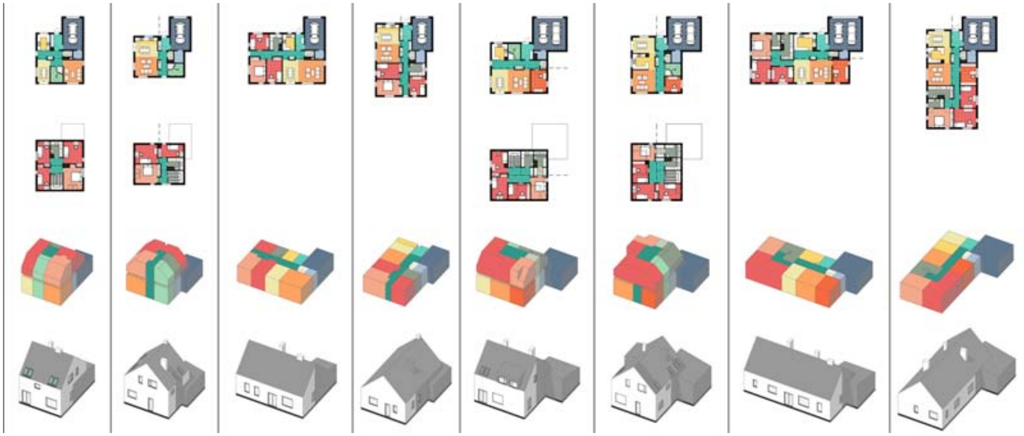

Figure 4
Exemplary system outcomes

tion and adjustment of the design to their needs. Prescribed in the system architects' design rules should allow conscious and informative self-configuration of houses. Therefore such tools may also give the opportunity to indirectly educate the public, by letting them practically interact with the design rules. Configuration process should be conceived as a reiterative process of understanding contradictory conditions, finding a solution, evaluation and deciding.

Figure 5
Homepose mobile application

The proposed framework for the development of the computer design tool integrates architectural design knowledge with customer willingness for participation in the design of their homes. Hence, to test the usefulness of the invented design system computer software is being developed. Although the computer system, in a form of a mobile application called Homepose (Figure 5), is still under development, it is important to discuss, at this stage, its assumptions and objectives in order to assure the relevance of final outcome. It is not clear, at this point, if customers purchasing new houses will be interested and capable to individually participate in the design process of such spaces.

ACKNOWLEDGEMENTS

An early version of this work was conducted during Kwieciński's Master Thesis at Faculty of Architecture at the Warsaw University of Technology. Special thanks go to Kuba Cupisz, who has contributed to this research by creating Homepose application.

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