Customized Housing Design

Tools to enable inhabitants to co-design their house

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In architecture, the individual needs and preferences of the end users need to be achieved in order to ensure a successful design. Standardized houses have been for long the reason for inhabitants' lack of satisfaction. The participation of inhabitants in the design process of their own houses is a crucial aspect to address housing customization, however there is a lack of effective tools to help inhabitants co-design their houses. Generative design solutions seem to be an effective way to address mass customization problem. In this paper we present a literature review on computer aided design systems that allow inhabitants to design, or partially design, their own houses. Existing solutions are classified in several categories (as generation process, target users, type of outcome, type of interaction, availability) regarding to what they accomplish and then analysed.

Keywords: *Customization, User participation, Co-design, Computer-aided design, Housing design systems*

INTRODUCTION

There is an identified need for housing customization that should address both social issues by increasing identity and personalization, and functional issues by incorporating the expertise of the designer. The participation of the final users in the design process is identified to be a crucial aspect for a successful design. This mass-customization problem needs to be approached with a generative design system.

Renowned practitioners as the group MVRD have been developing concepts to democratize architecture and empowering inhabitants. This democratization is enable by the fact that the final decisions are given to the user of the system and not to the architect which raises questions of authorship of as pointed out by Kolarevic and Duarte (2019). The aim of this paper is to present a literature review on the design computer tools that have been developed to enable the design of housing and targeted to be used or partially used by inhabitants. In this paper existing solutions are classified in several categories (as generation process, target users, type of outcomes, type of interaction, availability) regarding to what they accomplish and then analysed. The tools analysed in this paper support in some extend participatory and co-design although most of them are not used in the real-life design sector.

This paper is organized in four sections. In section two and three we introduce the core themes of the research which are Housing Customization, user participation and co-design (section two) and Generative Design Systems (section three). In section four

we present the classification of housing design system which is the main goal of the paper. We end the paper by presenting a discussion and conclusions.

HOUSING CUSTOMIZATION, USER PARTICIPATION AND CO-DESIGN

One of the most common difficulties in architectural design is to accommodate the specific wishes and requirements of all end users in the design process of their homes. As stated by Lo, Schnabel and Aydin (2016), "Providing housing is just a start, providing one that fits the individual needs families is the one of the next challenges.". In this line, enabling inhabitants to have control over their future house will assure this success and will democratize architecture for the society as a whole, by letting society have a voice and play an active role in the development of the housing industry. Architects have developed several concepts to enable houses to be customized by their inhabitants and by solutions that are predefined and delivered with the initial design project.

Society has been taken part of design processes in cases as housing, educational facilities and public spaces. Participatory processes and co-design initiatives through face-to-face participation methods such as meetings and workshops allow end users to take an active role while the architect acts as moderator. The Patio was a top-down initiative by the public administration in Hammarkullen, Sweden, which aimed to carry out a series of workshops and collaboration sessions in which citizens collaborated in the planning and construction of a stage in the public space (Stenberg, 2013). In the Netherlands, Álvaro Siza Vieira designed Punt en Komma housing complex in a participatory process, as part of the urban renewal of the Schilderswijk district of the Hague city. La Mémé, medical students' residence of the Université Catholique de Louvain (UCL), designed by Lucien Kroll in Brussels, is another example of a participatory process, where hands-on workshops were carried out between the architect and his team, UCL officials and the medical students to create a design to unify the campus.

The focus of the Open Building concept, developed by John Habraken (1972), is the creation of a building that, without knowing who the end users are, leaves its interior open, ensuring the necessary flexibility to accommodate a wide range of possible preferences and needs. Habraken proposes that the interior of the building is independent of its shape and develops the construction system Matura Infill System that frees the walls of the infrastructure, making it possible to change its location so that the interior of the building can be easily reorganized (Cuperus, 2001). Yona Friedman was another pioneer of concepts such as flexibility, adaptability and empowering citizens to decide on the interior of their own homes. His best-known works are the Manifesto - Mobile Architecture [3] and Mobile Architecture: 10 Principles of Spatial Urbanism [2] in which he proposes a utopian city, Ville Spatiale, which would be built in the airspace of a city. This environment would be flexible, so that the inhabitants could define the configuration of their own dwellings.

COMPUTER AIDED DESIGN SYSTEMS

Standardization allows the creation of mass-housing in a relatively quick and low-cost manner. However, inhabitants have individual needs that standardization cannot address. In this sense, the need for mass-customization is evident and can be aided by generative design tools which allow the generation of a large number of diversified solutions in an automated way. Since the last 40 years, work have been done to develop computational design tools to answer the need to create design alternatives that correspond to the needs of end users. The aim of such work is to develop intuitive and intelligent design tools that assist the inhabitants identifying their wishes and needs and in defining a housing design that responds to them. Parametric design systems that enable to create diversified design solutions by changing parameters and other computer rule-based design systems have been developed to answer the aims of customizations and diversification.

Parametric design is an algorithm-based method which changeable values of the parameters allow to manipulate the geometry and explore within a wide range of possibilities, in order to optimize the form and increase the efficiency on the design analysis (Dino, 2012). Parametric design, combined with BIM modelling, is being used by several offices and MVRDV have developed a set of design tools that enable to create designs controlled by parameters in the Functionmixer, Citymaker and Villagemaker (Zuidgeest, Burgh and Kalmeyer, 2013). The Citymaker, as well as the Villagemaker, were developed with the aim to be an open-source design system that includes citizen participation in order to create a city that responds to citizens demands. Shape grammars, introduced by Stiny and Gips (1972), are generative systems that generate designs, or composed shapes, by recursively applying shape rules (defined by shapes and spatial relations) to an initial shape and allowing to explore large solution spaces depending on the rules possibilities. Shape grammars have been applied to several fields and there are different purposes for its use: they can be used as analytical tools, to generate new designs and also to generate transformations. Stiny and Mitchell (1978) defined the Palladian Grammar, the first shape grammar written for the architectural field, which was able to generate the original designs of the Palladian villas and create hypothetical new ones in the Palladian style. Other more recent examples of shape grammars are the works of Duarte (2005) and Eloy (2012) that developed grammars with the aim to generate new housing designs or transformations, respectively, based on the preferences and needs of the end-users. There are non-commercial software and research solutions for housing design which are, or were, available as i_Prefab Home (Huang and Krawczyk, 2006), ModRule (Lo, Schnabel and Gao, 2015), Barcode (Madrazo et al., 2010) and Architectures (SmartScapes Studio SL, 2019). Besides generative design tools as the ones mentioned before, there are commercial software solutions for homeowners to design their houses (e.g. 3D Home Architect, Roomsketcher, IKEA design tool). Such tools enable citizens to develop their houses by customizing them to their needs and wishes. The designs these tools generate do not yet comply either with architectural good practices or with building regulation, and therefore somewhat mislead users. The next step in making these tools available is therefore including more architectural knowledge such that inhabitants indeed can take part in the housing design.

CLASSIFICATION OF HOUSING DESIGN TOOLS

In this part, an analysis is made on some computer systems that use technologies as auxiliary tools for the design of personalized housing. These systems are categorized by different characteristics to identify the strengths and weaknesses of each one. These categories include: 1) process of generating the solutions; 2) target users; 3) type of outcome; 4) type of interaction with the system; 5) availability of the system.

Generation process

- **Systems that generate in one step the final design of a new house**

Some systems aim at generating in one step the final design of a house showing it to the end user and omitting to him/her the stages of generation. These systems exist for both new construction and for refurbishment purposes. For new construction **Barcode Housing System** (Madrazo et al., 2010) automatically generates housing layouts that are filtered and presented to the user based on the requirements defined by the inhabitants. Also **i_Prefab Home** (Huang and Krawczyk, 2007) generates housing design and assists in selecting appropriate building components for prefabricated housing. **Haiti grammar** (Benrós et al., 2011) generates the design of customized Haiti Colonial houses for post-Earthquake, and **Shaper GA** (Taborda et al., 2018) generates different customized wood housing solutions based on the requirements introduced by the user. The system

presents a set of possible solutions that accomplish the requirements through which user can navigate to choose the final design. For housing transformations and refurbishments **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015) enable inhabitants to obtain a customized automatic design for the refurbishment of their house. The concept of the **Bourgeois houses Porto grammar** (Coimbra and Romão, 2013) is also to provide a tool to create alterative design solutions for the refurbishment of a specific house type in Oporto. The **Vernacular Hayat houses grammar** (Colakoglu, 2005) purpose is to generate new house designs based in original language of Hayat style. Some systems aim at generating a design of a house that already exists for analysing propose. Analytical solutions with shape grammars are used in most of these cases. Examples are: the Malagueira design system, a shape grammar design system created by Duarte (2005) that generates houses in Malagueira designed by Siza Vieira (tool **MALAG** by (Duarte and Correia, 2006)); the **Favela Rocinha houses grammar**, in Brazil, (Dias, Gani and Chokyu, 2013); the **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995); and the **Traditional Turkish houses grammar** (Ça□daş, 1996).

- **Systems that generate by steps the design of a new house**

Some systems aim at generating a design of a new house step by step allowing users to make decisions during the house design generation. Some examples of such systems are **ModRule** (Lo, Schnabel and Gao, 2015), **Group Forming** (Ong, Janssen and Lo, 2013), **Layout Generation** (Veloso, Celani and Scheeren, 2018), **A_Shaper** (Santos et al., 2018), and **HouseMaker** (MVRDV and Axis.fm, 2012). Also, in the commercial sector there are systems that support the design of houses or part of houses in a step by step manner. Examples are the **IKEA Home and Kitchen Planner** [4], the **Room Sketcher** [5] and the **Sweet Home 3D** [1] to create customized houses and **Architectures** [6] that allows the user to create mass-housing design.

- **System that generates in one step a part of the house and leaves a part to be generated by steps of a new house**

Some other systems generate in one step part of the house and leave other parts to be generated step by step, allowing users to make decisions during the house design generation. The **ABC based Customized Mass-Housing generator** (Benrós and Duarte, 2009) is a tool to generate and support the design of mass-customized houses. A 3D model is automatically generated based on the decisions taken by the user and the tool then assists the user in the spatial organization of the functional units. Also the **web-based user-oriented tool for universal kitchen design** (Ma, 2002) generates design solutions that are retrieved to present the most fitted solutions based on the family's requirements and also supports the user, on the final stage, to choose the appropriate kitchen equipment based on the rules of universal design. The **platform for consumer participative design open buildings** (Mcleish, 2003) is a system that enables inhabitants to co-design their houses/studios in an open building way. The system generates the initial design and also allows user to refine the layout step by step.

Target users

- **Architects**

Some of the systems under analysis are according to the authors designed to be used by professionals. Some of them, as **Bourgeois houses Porto grammar** (Coimbra and Romão, 2013), **Vernacular Hayat houses grammar** (Colakoglu, 2005), **Favela Rocinha houses grammar** (Dias, Gani and Chokyu, 2013); and **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995) are designed for architects. For some of them the use still presupposes design and programming skills that non-designers do not have. The **Traditional Turkish**

houses grammar (Ça□daş, 1996) is designed, according to the authors, to facilitate the understanding of the Turkish houses by architecture students in order to incorporate this knowledge in future housing designs.

- **Clients**

Other systems are targeted at the client himself, whether is the end user (inhabitants) or the building promoter. Examples of systems target for inhabitants are **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015), **Shaper-GA** (Taborda et al., 2018), **A_Shaper** (Santos et al., 2018), **Web-based user-oriented tool for universal kitchen design** (Ma, 2002), **IKEA Home and Kitchen Planner** [4] and **Sweet Home 3D** [1]. The **HouseMaker** (MVRDV and Axis.fm, 2012) is also targeted for inhabitants and allows them to remotely communicate with family or friends in order to define the characteristics of the house while they are assisted by the operator. **Architectures** [6] and its online mass-housing design system is designed to be used by the promoter of a building block. **MALAG** (Duarte and Correia, 2006), **i_Prefab Home** (Huang and Krawczyk, 2007) and **Room Sketcher** [5] can also be handled by architects but the main target public are the inhabitants.

- **Architects and inhabitants**

There are also collaborative systems that allows the participation of different stakeholders and also the communication between multiple end-users. **Barcode Housing System** (Madrazo et al., 2010) and the **platform for consumer participative design open buildings** (Mcleish, 2003) enable the participation of designers, end-users and manufacturers at different stages of the process. **ModRule** (Lo, Schnabel and Gao, 2015) and **Group Forming** (Ong, Janssen and Lo, 2013) are handled by architects and inhabitants at different stages, but also allow the collaboration between multiple end users in order to create mass housing solutions that every user is satisfied with. Layout Generation (Veloso, Celani and Scheeren, 2018) is used by architects and inhabitants at each stage and also allows the collaboration between them at the final stage to choose finishes. The **ABC based Customized Mass-Housing generator** (Benrós and Duarte, 2009) and the **Haiti grammar** (Benrós et al., 2011) are used by architects and foresee the inhabitant to be present during the decision making process.

Type of design outcome

- **Simplified floor plan**

Some systems deliver at the end a simplified floor plan which e.g. defines the functional areas of the house but does not give construction information. **A_Shaper** (Santos et al., 2018) and **Shaper-GA** (Taborda et al., 2018) give as outcome a simplified layout of a house. This layout is based on a grid composed by squares of 60x60cm, a set of squares composes a room, each type of room as a different colour. **Vernacular Hayat houses grammar** (Colakoglu, 2005), Favela Rocinha houses grammar, (Dias, Gani and Chokyu, 2013); **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995); and **Traditional Turkish houses grammar** (Ça□daş, 1996) results are represented with shapes that figure schematic floorplans.

- **Detailed floor plan**

Other systems generate detailed floorplans with indication of walls, openings and large-scale construction information as materials and construction systems. Such systems are **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015), **Bourgeois Oporto houses transformation grammar** (Coimbra and Romão, 2013), and **Group Forming** (Ong, Janssen and Lo, 2013). **Web-based user-oriented tool for universal kitchen design** (Ma, 2002) floorplans also include kitchen equipment.

- **Drawings and 3D house design**

In addition to detailed drawings, some systems generate 3D models that provides interior or aerial views. In the **HouseMaker** (MVRDV and Axis.fm, 2012) the

results of the options made are presented in 2D or 3D, according to the type of element that is being defined and it can be shared, printed, sent by email and purchased. Also **Room Sketcher** [5] provides 2D floorplans, interior views and a 3D walkthrough mode, as well as **Barcode housing system** (Madrazo et al., 2010) and **Module** (Lo, Schnabel and Gao, 2015) that generate detailed floorplans from simplified representations. The latter also allows a virtual reality visualization with FuzorVDC (www.kalloctech.com).

- **Drawings, 3D house design and Lists**

Other systems generate 2D drawings, 3D models that provide different types of visualization and lists of building elements and budget. Examples of such systems are the **i_Prefab Home** (Huang and Krawczyk, 2007) system, **ABC based customized mass-housing generator** (Benrós and Duarte, 2009), **Haiti grammar** (Benrós et al., 2011), **MALAG** (Duarte and Correia, 2006), and **Layout generation** (Veloso, Celani and Scheeren, 2018). The **platform for consumer participative design open buildings** (Mcleish, 2003) can also generate list of components that reflect their positions and finishes options made by the user, **Sweet Home 3D** [1] generates printable furniture list besides the floorplan and 3D, and the **IKEA Home and Kitchen Planner** [4] generates the list of all the store's products included in the design. **Architectures** [6] generates a viability analysis and the entire architectural definition and construction elements, with building services, prepared to city permits. The outcome is generated in CAD, BIM and Excel formats.

Type of interaction with the system

- **Start by defining user preferences**

In this category we include all the systems that generate design solutions based on initial user requirements and users can change the requirements to achieve different solution until they are satisfied. Examples of such systems are: **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015) that starts by the introduction of users requirements; **i_Prefab Home** (Huang and Krawczyk, 2007), where a user is defines the requirements through questionnaires and icon selection and then is able to select the preferred solution and choose the finishes; **MALAG** (Duarte and Correia, 2006), that generates on PROGRAMA interface the design brief as a list of space requirements to be introduced on DESIGNA interface in order to create the design solution; and **Shaper-GA** (Taborda et al., 2018), that generates a bank of solutions based on the requirements data introduced, through which user can navigate until find the most fitted or change the requirements to generate different ones. Also the **Web-based user-oriented tool for universal kitchen design** (Ma, 2002) is able to generate solutions based on the information introduced and update the results as the requirements are changed. This tool also enables to drag and drop universal design kitchen products and assists the user with recommended solutions. The refining process of the design generated by the **platform for consumer participative design open buildings** (Mcleish, 2003) is made with physical models on an interactive table and the system updates the design, as the user moves the models, identifies problems and suggests solutions. The **HouseMaker** (MVRDV and Axis.fm, 2012) categorizes all the elements of a house regarding materials, shapes, rooms, layout, etc. Although there is not a mandatory sequence, user starts by defining the room characteristics.

- **Start not by defining user preferences**

In this category we include all the systems that the generation process does not start by the introduction of user preferences. **ModRule** (Lo, Schnabel and Gao, 2015) and **Group Forming** (Ong, Janssen and Lo, 2013) start by generating a grid with parameters and spatial rules defined by the architect and then multiple end users negotiate with each other to fill the grid and define their houses. The interior layouts are defined and ModRule also allows to drag room types and make connections. In other mass housing

systems, referred below, architects start with the definition of the overall rules and characteristics of the building, with fixed elements and common spaces, and then the inhabitants define the interior of their houses. Such systems are **Barcode housing system** (Madrazo et al., 2010), **ABC based customized mass-housing generator** (Benrós and Duarte, 2009). Also **Layout generation** (Veloso, Celani and Scheeren, 2018) interaction is performed by steps where initially an open space is divided into smaller rooms and then the system presents the next possible steps. In commercial systems, as **Room Sketcher** [5], **Sweet Home 3D** [1], and **IKEA Home and Kitchen Planner** [4] users can choose architectonic elements and with them design a house in a semi random way. **A_Shaper** (Santos et al., 2018) starts with the generation of a grid that represents the dimension of the house, and the sequence of actions includes assigning in a specified order the entrance, the semi-public spaces and, at the end, the private zones. **Architectures** [6] starts with the definition of the external configuration of the building. The typologies of dwellings and interior layout are then defined by the user and is also possible to control the façade characteristics The authors of **Bourgeois Oporto houses transformation grammar** (Coimbra and Romão, 2013) do not define the type of interaction although the process implies defining functional zones and further the division into smaller rooms on each floor until reaching the final result. **Haiti grammar** design system (Benrós et al., 2011), **Vernacular Hayat houses grammar** (Colakoglu, 2005); **Favela Rocinha houses grammar** (Dias, Gani and Chokyu, 2013); **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995); and **Traditional Turkish houses grammar** (Çaldaş, 1996) comprehends different stages of rule application although the authors do not specify the mode of interaction of the user with the systems.

Availability of the system

- **Available online for free**

IKEA Home and Kitchen Planner [4] is available online for free at kitchenplanner.ikea.com/au/UI/Pages/VPUI.htm. **Room Sketcher** [5] can be used online at planner.roomsketcher.com, and it is possible to install the application for using in the computer or a tablet device. **Sweet Home 3D** [1] is also a free system that can be used in two ways, online at www.sweethome3d.com/SweetHome3DOnline.jsp or using the application version.

- **Available under request/payment**

In **Room Sketcher** [5] not every feature is available for free, the system has a premium subscription that enables users to have access to every feature. A demo of **Architectures** [6] is available under request at architechtures.com.

- **Not available**

Some systems have been implemented or partially implemented as prototypes and are not available online for free as well as not announced to be available under request. Examples are **A_Shaper** (Santos et al., 2018), **Shaper-GA** (Taborda et al., 2018), **ModRule** (Lo, Schnabel and Gao, 2015), and **platform for consumer participative design open buildings** (Mcleish, 2003). Also prototypes of **ABC based customized mass-housing generator** (Benrós and Duarte, 2009) and **Haiti grammar** (Benrós et al., 2011), developed to run on AutoCAD and Revit Architecture software, respectively, are not available. **Rabo de Bacalhau Transformation Grammar** (Eloy and Duarte, 2015), partially implemented by Strobbe (Strobbe et al., 2016), **HouseMaker** (MVRDV and Axis.fm, 2012), **Web-based user-oriented tool for universal kitchen design** (Ma, 2002), **i_Prefab Home** (Huang and Krawczyk, 2007) and **Layout Generation** (Veloso, Celani and Scheeren, 2018) are also not available. **Barcode Housing System** (Madrazo et al., 2010) is not available online as a design

tool although the system explanation is available at www.barcodehousing.net/english.html. **Group Forming** (Ong, Janssen and Lo, 2013) prototype has been implemented as a web application and is currently not available although an explanation about the system is available at vimeo.com/26638743. **MALAG** prototype (Duarte and Correia, 2006) was envisioned to be used online or as a PC application but the system is not available as a design tool. There are also shape grammar systems that intended to generate housing designs although they have not been implemented as computational systems. **Bourgeois Oporto houses transformation grammar** (Coimbra and Romão, 2013); **Vernacular Hayat houses grammar** (Colakoglu, 2005); **Favela Rocinha houses grammar** (Dias, Gani and Chokyu, 2013); **Taiwanese traditional vernacular dwellings grammar** (Chiou and Krishnamurti, 1995); and **Traditional Turkish houses grammar** (Ça□daş, 1996) are examples of such design systems.

Resume

This section presents a classification diagram, in the form of a table (Table 1). The table summarizes the characteristics of the systems analysed above, within the defined criteria. The Av/Imp column shows the characteristics analysed in the system availability criterion; SM is a complement to the type of interaction with the system criteria, and defines whether the systems have (or not) the ability to directly manipulate the space; Process refers to the analysis made to the generation process; Users is for the target users; and, finally, Outcome representation presents the type of design outcome.

DISCUSSION AND CONCLUSIONS

The previously mentioned academic studies and commercial tools were designed to help the customization of housing. All of them have a general aim of allowing the design of housing but they differ in the way they do it and to whom they were designed to. Some allow a direct collaboration between architects and inhabitants, others are designed only for architects use, and others to be used just by inhabitants. Different modes of visualization are used, as 3D elements or schematic elements, that may not be very effective in the perception of space by non-specialists. Commercial examples allow 3D visualization of different modes and angles since they are generally intended to be used by inhabitants, who have access to user-friendly drawing tools for direct manipulation of space without needing technical knowledge. These tools generate designs that do not yet comply either with architectural good practices or with building regulation, and therefore somewhat mislead users. Other commercial solutions are intended for professional use, not including inhabitants in the design process of their homes. We also identified that most of the mentioned systems are important contributions for the mass-customized design problem, but they are not available to the design sector and therefore cannot be used in real life design scenarios. We can then conclude that there is still a lack of solutions that are cumulatively intuitive to be used by the inhabitants, make it possible to generate a wide range of customized house designs and comply with good architectural practices and construction regulations. As said by Kolarevic and Duarte (2019) in the future it might happen that customers can fully customize, via websites, their house layouts and make all the decisions regarding the design of their house. Such a possibility would democratize architecture giving room for co-design and not moving away architects from the design process. Presented tools gave a step to allow this democratization but the ones who include architecture knowledge and intuitive interfaces are still not available to the general public. The next step in making these tools available is therefore to include more architectural knowledge and make tools more user friendly for non-designers such that inhabitants indeed can take part in the housing design.

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Table 1
Synthesis of system's characteristics. Process – GN (Generate New design); SN (Support New design); G/SE (Generate or Support Existing design). User – A (Architect); I (Inhabitant); O (Other). Outcome representation – SP (Simplified Plan); DP (Detailed Plan); SD (Simplified Drawings); DD (Detailed Drawings); 3D (3D model); L (Lists). SM – Direct manipulation of space: Yes, No. Av/Imp – Availability and Implementation: Available, Prototype not available, Not available.

Name	Process			Users			Outcome representation						SM	Av/ Imp
	GN	SN	G/SE	A	I	O	SP	DP	SD	DD	3D	L		
Taiwanese traditional vernacular dwellings grammar (1995)			X	X			X						N	N
Traditional Turkish houses grammar (1996)			X	X			X						N	N
Web-based user-oriented tool for universal kitchen design (2002)	X	X			X			X					Y	P
Barcode Housing System (2003-10)	X			X	X	X				X	X		N	P
MALAG (2005-10)	X		X		X			X			X	X	N	P
Vernacular Hayat houses gramar (2005)	X			X			X						N	N
i_Prefab home (2006-07)	X				X					X	X	X	N	P
ABC based Customized Mass-Housing generator (2007/09)	X	X		X	X					X	X	X	Y	P
Haiti grammar (2011)	X			X	X					X	X	X	N	P
RdB transformation grammar (2011-16)	x				X			X					N	P
Group Forming (2013)		X		X	X					X			Y	P
Bourgeois Oporto houses TG (2013)	X			X				X					N	N
Favela Rocinha houses grammar (2013)			X	X			X						N	N
Digital tool for customized mass housing design (2014)		X		X	X				X		X		N	P
ModRule (2014-16)		X		X	X			X			X		Y	P
Shaper-GA: Wood mass customized housing (2016-18)	X				X		X						N	P
A_Shaper: Wood mass customized housing (2016-18)		X			X		X						N	P
Layout Generation (2018)		X		X	X					X	X	X	N	P
A platform for consumer participative design open buildings (2003)	X	X		X	X			X			X	X	Y	P
HouseMaker		X			X					X	X		N	P
IKEA home and kitchen planner (1999)		X			X					X	X	X	Y	A
Room sketcher		X			X			X			X		Y	A
Sweet home 3D (2006)		X			X			X			X	X	Y	A
Architectures (2019)		X			X					X	X	X	Y	A

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