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A Study on Interaction and Visualization Modes

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Tools for the Co-designing of Housing Transformations: A Study on Interaction and Visualization Modes

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Abstract

In this paper we present and assess tools for visualizing architectonic modifications of existing housing in co-design projects with inhabitants. These tools should enable inhabitants to explore and understand design variations of alterations of their houses. This contribution is part of ongoing research on the use of artificial realities for supporting the transformations of existing housing in architectonically responsible ways. Such transformations may be needed after the delivery of housing, say after five years or later, due to changed regulation, the need of updates or changed living conditions of inhabitants. For arriving at architectonically responsible transformations, we use shape grammar system for defining possible modifications of the housing. For empowering inhabitants to understand and explore these modifications to their housing, we develop a transformation grammar tool—MyChanges—to visualize the modifications by three visualization modes, from fully immersive to non-immersive. Interviews and tests with real inhabitants were performed, and preliminary conclusions show that a tool like the MyChanges would have a good acceptance among inhabitants.

Keywords

Participatory design • Generative design tool • Virtual reality • Users' feedback

1 Introduction

Since some decades, architecture promotes a participatory approach that gives inhabitants the power to co-determine architectural design. This approach leads theoretically to solutions that are closer to the inhabitants' desires and ensures an alliance between architectonic quality and inhabitant satisfaction. Personalization and appropriation is seen as an important property that creates a sense of belonging to a place and therefore improves the quality of life of inhabitants [1, 2]. But architecture also advances the "authorship" position that consists on maintaining the architects' concepts and decisions when refurbishing or altering houses. This can mean that no changes are allowed, or only those that architects sanction.

In an interview, Rem Koolhaas refers to the architect as someone who judges what is beautiful and what is not beautiful, what should stay and what should disappear, what should be shown and what should be hidden. Koolhaas continues saying that architects judge in relation to priorities in architecture and that those are personal judgments that aim at preserving the purity and freedom at stake [3].

The common strategy used by architects for both allowing personalization and maintaining the authorship position is offering several design solutions such that inhabitants can personalize their houses by picking the one of their liking. Examples of housing projects in which this strategy was followed are the Malagueira neighborhood in Évora, Portugal, and Silodam and the Borneo Sporenburg neighborhood in Amsterdam, the Netherlands. In Portugal, SAAL (*Serviço de Apoio Ambulatório Local*) was the largest social participation process in housing design that covered

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territories from north to south of the country. The SAAL program was created to respond to a deficit in housing with good habitable conditions. Under this program, several housing complexes were built and some of them enabled citizens' participation in the design of their own homes. Although it was not developed during the SAAL period, the Malagueira neighborhood, designed by the architect Álvaro Siza Vieira, is a paradigmatic example of a participatory process in the spirit of the SAAL intention. The design of the Malagueira houses was developed in collaboration with the future inhabitants, and this process had impact on some design decisions, e.g., changes in the façades so that the houses had greater contact with the street than what was originally designed by the architect [4].

This first strategy seems, however, not to be enough since it covers only personalization during the design and construction of housing, whereas personalization will also occur at later stages. A further strategy adopted in architecture is therefore to also define possible future changes to houses. For instance, Siza Vieira laid down a set of rules that allowed the evolution of houses in Malagueira from one to five bedrooms in order to respond to the evolution of families through time. The set of rules Siza Vieira left also included other aspects of the design, e.g., limits to the height of the houses, the size of the openings, and the option to paint the paneling on the exterior walls and frames around windows and doors for respecting the vernacular language of the region [5, 6]. However, Malagueira was under huge criticism by the inhabitants and in the press. In fact, Malagueira was several times referred to as the "Arab quarter" looking monotonous and inhuman [4, 7]. While local authorities and some inhabitants who were directly involved in the process defended the good collaborative process and emphasized the qualities of the project, other inhabitants expressed discontent and made changes to the houses over time. Some of these changes respected the rules defined by the architect, and others were carried out illegally, such as the placement of stairs to the terrace of the upper floor.

In this paper, we present and assess tools that support this further strategy for architecturally responsible personalization. The tools are for defining and visualizing architectonic modifications of existing housing in co-design projects with inhabitants and should enable inhabitants to understand and explore modifications of their housing. This contribution is part of ongoing research on the use of artificial realities for supporting the transformation of existing housing in architectonically responsible ways. Such transformations may be needed after their delivery, say after five years or later, due to changed regulation (e.g., new regulation about safety or sustainability), the need of updates (e.g., new technical infrastructure), changed living conditions of inhabitants (e.g., the need for an extra room or working place) or other wishes by inhabitants (e.g., decoration). For arriving at architectonically responsible transformations, we use shape grammar system as developed by Eloy [8] and Eloy et al. [9] for defining possible modification of the housing. For empowering inhabitants to understand and explore these modifications to their housing, we developed tools to visualize the modifications. The longer-term goal of this research is to develop a transformation grammar tool to be applied to existing houses and to test it with real inhabitants to determine the acceptance by the inhabitants of the tool.

This paper is divided into three main sections. First, we present a brief state of the art regarding the view in architecture related to diversity, co-design and the use of digital tools to enable diversified solutions to be created automatically by a computer and used by inhabitants. Second, we present the development and test of a design system interface designed to enable inhabitants to obtain design solutions to alter their houses. We end with discussion and concluding remarks.

2 Diversity, Co-design and Generative Design Systems

2.1 Diversity and Co-design

Creating diversity is a goal that has been in the mind of architects for decades. This aim, when applied to housing design, would enable to satisfy inhabitants' by giving them solutions that would fit individual needs and aspirations. Pioneering work by John Habraken in the 1960s [10] on the Open Building approach was an important moment when architecture made an effort to address diversity in design responding to the individuality of the inhabitants. More recently, the incremental housing approach promoted by Reinhard Goethert [11] and the Elemental solutions for social housing [12] are successful examples of promoting diversity in architecture. Also the Dutch architectural office MVRDV is for long concerned with how architects can "handle the endless individual desires of prospective homebuyers" [13] and buildings like Silodam are attempts to respond to this question.

In the beginning of the twenty-first century, the introduction of sustainability issues and the reemergence of participatory and collaborative processes in architecture reintroduced the social debate in the architecture practice after a decade of star-architecture focuses on extraordinary and mediatic buildings [14]. Indeed, new thinking emerged about the relations between the place and its users instead of the focus being mainly on building as isolated unities that expresses subjectivity.

According to De Koning et al. [15] and Faliu et al. [16], co-design consists of the collaboration of all stakeholders in a project that reflects decisions taken together. These authors argue that in a participatory process, there are several steps

needed from the provision of information, to the development of ideas and requirements within all stakeholders. Engaging people to participate in this process is easier if they are attached to the places to be designed. As Sanoff [17] says "citizens do not care about projects until they start affecting them."

2.2 Generative Design Tools

Generative design computer tools have been developed in the last 40 years to respond to the need to create alternatives of design. Shape grammar design systems [18] aim to explore large solution spaces in an iterative manner. As such, they can form an excellent means to support designers and architects in finding diversified design solutions.

Several authors have been researching how shape grammars can be applied to housing design and how they can include the needs of inhabitants. Some of the developed systems generate new designs based on the requirements defined by the user. These tools may start by inquiring the user for input data through questionnaires or image selection and icons, and then automatically generate solutions that best suit these requirements. Other options are to present to the user a step-by-step design generation which guides the user to the final design. MALAG [19] is a system that allows both the creation of new construction and the reproduction of existing houses using the Malagueira shape grammar [20]. Another system, the Layout Generation system [21], allows the user to define by stages the house layout while all the decisions taken are visualized. This system uses shape grammars to generate design solutions customized to the inhabitant. HouseMaker© (MVRDV and Axis.fm, 2012) is a vision developed by the architectural office MVRDV that all together hands over the design of houses to the future inhabitants. The aim was to develop a tool that categorizes all the elements of a house and offers a user-friendly interface with which inhabitants could customize their future houses regarding materials, shapes, rooms, sizes, layout, etc.

In the present research, we focus on transformation grammars which are grammars that enable the transformation of existing designs into adjusted ones [22]. Examples of these grammars applied to housing design are the work of Colakoglu [23] that aims at modifying traditional Hayat houses to fit contemporary wishes, and the work of Eloy [8] on the development of a transformation grammar to refurbish a specific housing type, Rabo-de-bacalhau in Lisbon, to meet the requirements of new life styles.

2.3 Representation and Visualization

Architects use several methods to describe and register their designs and most of them are used for centuries. Bi-dimensional floor plans, elevations and sections are very common although clients, non-designers, such as inhabitants, usually have difficulty in understanding these descriptions. In the last decades, computers have enabled new methods for representation and visualization that are more natural and closer to reality than ever before. Virtual reality (VR) and augmented reality (AR) are examples of such methods.

VR is referred as a completely virtual and immersive environment that follows or not the physical properties of real world [24]. To use VR, one needs to have a large set of screens (CAVE, Powerwall, etc.) or a head-mounted display (HMD). CAVE technology allows a relationship between the user and the virtual environment, where the user is totally immersed in a real-scale projection. HMD technology also allows great immersive although usually used on an individual basis contrary to the collective use of CAVE where several users can have a shared experience.

AR allows the interaction between real and virtual objects at the same time [25]. AR can be visualized through smartphones, tablets or HMD, like Microsoft HoloLens as well as large projections where people can observe and analyze the combination of the real environment with virtual elements.

Currently, there are several market software that enable interactive VR experiences; examples are MindeskVR[1] and FuzorVDC.[2] Both are software with interfaces for real-time editing projects making it possible to navigate, edit and modeling 3D CAD in a totally virtual environment without having to export the models. Enscape[3] is a plug-in that allows to walk-through a 3D model in real time (Revit, SketchUp, Rhino and ArchiCAD). Unity[4] and Unreal Engine[5] are two platforms for 3D creation for immersive and interactive virtual experiences, where models can be done in this software or imported from other 3D modeling software.

3 MyChanges

3.1 Goals and Methodology

In Eloy et al. [9], we presented a post-handover shape grammar for introducing inhabitants' wishes in the transformation of individual houses of the Malagueira housing complex by Álvaro Siza Vieira. This grammar was developed by a group of architects during a workshop and later refined, for capturing a balance between the visible

[1] https://www.umindeskvr.com.
[2] https://www.kalloctech.com.
[3] https://www.uenscape3d.com/.
[4] https://www.uuinty.com.
[5] https://www.unrealengine.com/en-US/.

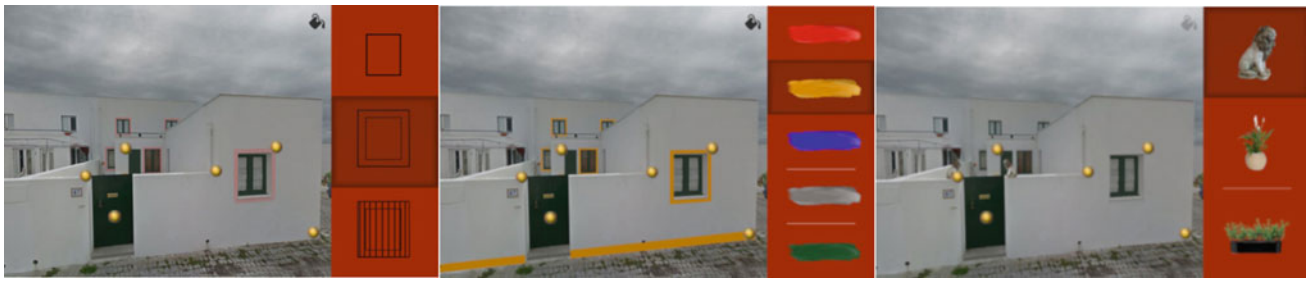

Fig. 1 Mock-up MyChanges, (left) window frame option selected, (middle), color menu and color selected (right) adornment menu and selected

transformations that Malagueira inhabitants did to their houses and the original architecture of Siza Vieira.

The goal of the research done for the present paper is to develop this Malagueira transformation grammar tool, from now on addressed as MyChanges, and test it with inhabitants of the Malagueira housing. The methodology used comprises four stages:

1. development of the Malagueira transformation grammar, done in [9];
2. development of a mock-up of the interface of MyChanges;
3. development of different modes of visualization from less to more immersive and from less to more visibility throughout the surrounding areas of the house; and
4. testing of MyChanges and the visualization modes with real inhabitants.

3.2 MyChanges Interaction and Visualization Development

The entire experience of MyChanges comprehends two main parts: the shape generation and the visualization.

The shape generation is currently not implemented in computer software but based on a simulation that reproduces some of the generation possibilities of the grammar. Although the grammar defined in [9] applies to all possible Malagueira facades, only one façade was used for the simulation.

The mock-up of the MyChanges interface is divided into two zones: first, a sidebar that corresponds to the menu, and, second, the middle area where a static image of the house façade to be customized is displayed. The customizable elements in the façade are identified with dots, on which the user can click so that the options appear in the side menu (Fig. 1). These elements are windows, doors, gate, wall, ornaments and railings. There is also an icon in the upper right corner of the viewing area that allows access to the color options of the wall paintings (Fig. 1). This icon is disactivated when the option selected does not allow painting (Fig. 1, right). The goal is that users can combine the customization of several of these elements as they prefer. Due to software limitations, in this mock-up it is only possible to reach predefined solutions.

To reach the result, the user clicks on the customizable element tag on the façade element he/she wants to customize and select the customization option he/she wants from the menu. This step is repeated until the user is satisfied with the drawing and by clicking on the color icon, which appears as soon as a paintable personalization is activated, he/she can select the color to be applied to all paintable elements. The result is visualized in a non-immersive screen-based static image superimposed on a photograph of one original façade of the house.

For visualizing the outcomes, we developed three different possibilities:

1. a non-immersive screen-based visualization using a tablet and where the final design is visualized as a static image;
2. a semi-immersive visualization using a smartphone and where the final design can be seen by a 360º render of the site; and
3. a fully immersive visualization using an HMD and where the final design can be freely navigated by the user.

The non-immersive screen-based visualization (A) uses a photo of a house in the neighborhood and superimposes digital elements as wall, window and door frames, and decoration (Fig. 1).

For the semi-immersive visualization using a smartphone (B), we modeled in Autodesk Revit[6] a representation of the Street Malagueirinha. With Enscape's library we add environment, sky, vegetation, cars and people, that were placed in the Revit model. After detailing the 3D model, we rendered a 2D panorama to be used in a smartphone screen (Fig. 2). For seeing the image using a smartphone, we used the app VR Media Center.[7]

[6] https://www.autodesk.pt/products/revit/overview.
[7] https://play.google.com/store/apps/details?id = com.xojot.vrplayer&hl = en_US.

Fig. 2 Non-3D 360° image

Fig. 3 Navigation in VR

For the fully immersive visualization using the HMD Oculus Rift[8] (C), we used the same Revit model previously made. In order to create a simulation of the neighborhood of Malagueira, we grouped three streets with three different customized façades so that users, if wanted, could navigate through the model. To place this model in VR mode and see it in a fully immersive way, we imported an FBX file exported from Revit into Unity 2019.2.12f1 software. Through asset store of Unity, we add all environment elements, as well as street sounds and people (non-player character—NPC) with movement (Figs. 3 and 4). The built model from Unity was then used in Oculus Rift.

3.3 Experiment

The following protocol refers to the experiments that were performed with real users (inhabitants of the Malagueira neighborhood) to assess the MyChanges tool.

[8]https://www.oculus.com/rift/.

Fig. 4 Customized house in VR with animated NPC

The goal of the experiment was to assess:

- The satisfaction of users with such a tool regarding the customization possibility that it offers to the design of the façade of their house. This satisfaction was measured not just regarding the customization possibilities presently encoded but also about the idea of customizing through such an app.
- The satisfaction of users regarding three modes (A), (B) and (C) of visualization of the final designs of the façade, as described above.

The different ways (A, B and C) of representing the transformed façade of the house were given to experimental subjects in order to obtain their feedback regarding the potential of the tools. Tests were done with inhabitants of Malagueira and took place in February 2020. Participants were recruited from the neighborhood in cafes and their offices from 10 a.m. to 6 p.m. for one day. In total, 12 inhabitants took part of the experiment, seven women and five man with an average age of 59 years (SD = 12.2).

The protocol used to perform the experiment is as follows. Participants were approached by three researchers who:

1. Explained the goal of the study and ask for their permission to participate and gave the informed consent form to sign.
2. Shown the tablet with the generative design mock-up *MyChanges* and explained the generation possibilities, guiding the participant when using the system.
3. Gave the participant Questionnaire 1 to fill and offered support to the participant with filling it.
4. Shown the participant three modes of visualization (these modes of visualization were presented to different participants altering the order): (A) A static image of the transformed façade using a tablet; (B) A 360º render of the street with the transformed façade, visible using a smartphone; (C) A VR navigable model of the street with the transformed façade, visible using a HDM (Fig. 5).
5. Gave the participant Questionnaire 2 to fill and offered support to the participant with filling it.

3.4 Results

Results of both Questionnaires 1 and 2 are shown in Table 1.

Questionnaire 1 was composed of three questions that focused on the usefulness of MyChanges. When participants were asked if the tool is helpful for inhabitants to change the outside of their houses (Q1), the average of participants indicated 4.33 (SD = 1.15), which confirms that they consider the tool helpful.

The average of participants indicated 4.50 (SD = 1) when asked if they would use the tool in case they wanted to change the outside of their house (Q2), which indicates a high level of acceptance and intention to use.

When asked if they would be happy to use this tool alone, or with their family or friends (Q3), the average of participants indicated 4.42 (SD = 1.16), which says that they would be pleased to use the tool accompanied by friends and family.

Questionnaire 2 was composed of seven questions, five close and two open questions, that focused the use of the interface of MyChanges.

Fig. 5 Participants during the experiments, (left) using the MyChanges tool, (middle) using the smartphone to visualize and (right) visualizing with the HMD

Table 1 Responses of Questionnaires 1 and 2

			Questionnaire 1			Questionnaire 2				
Gender		Age	Q1	Q2	Q3	Q4	Q6	Q7	Q8	Q9
F		44	4	5	5	*A*	*A*	1	5	NA
F		44	5	5	5	*A*	*A*	3	5	5
F		60	5	5	5	*C*	*C*	5	1	5
F		67	5	5	5	*C*	*C*	4	2	5
F		67	1	3	1	*A*	*A*	5	1	1
M		67	5	5	5	*B*	*C*	5	3	5
M		85	4	2	4	*C*	*C*	1	4	3
M		47	5	5	5	*A*	*A*	5	2	5
F		68	4	5	5	*A*	*B*	5	2	5
M		56	5	5	5	*C*	*C*	5	2	5
F		52	5	5	4	*C*	*C*	5	4	5
M		55	4	4	4	*A*	*A*	4	5	5
F = 7	*M*	59.33	4.33	4.50	4.42	*A* = 6	*A* = 5	4.00	3.00	4.45
M = 5	SD	12.12	1.15	1.00	1.16	*B* = 1	*B* = 1	1.54	1.54	1.29
						C = 5	*C* = 6			

NA—the participant did not answer. Questions 1, 2, 3, 7, 8 and 9 where answered using a scale from 1 to 5 being 1 the lowest score and 5 the highest score

In the beginning of this questionnaire, participants were asked "which way of looking at the changes do you prefer to use?" (Q4). Six participants chose A (tablet), one chose the B (smartphone) and five chose C (HMD). When asked to explain their choice (Q5), most participants that chose A said that their preference was related to the fact they could simulate changes in the table and to the fact it is simpler to see. Participants that chose C justified by saying the "it looks real", "you fell in the place" and the "image is bigger". These results let us think that, if the transformation tool was implemented in VR, there was a chance that people would prefer an HMD to both simulate changes and visualize. There was only one participant that chose B, and the reason was that this medium gives him a global view of the surrounding areas.

Participants where then asked which way of looking at the changes made them better understand how their house will look like? (Q6). Five participants chose A (tablet), one chose the B (smartphone) and six chose C (HMD). Also, in this question responses were, as in question 1, divided between A (tablet) and C (HMD). There was a correspondence between choosing the same device in both questions 4 and 6. There were two participants who chose differently from question 4 to question 6, and it is interesting to observe that both chose a more immersive and complete view in the second question (B → C and A → B).

Regarding the importance of observing the whole street when exploring changes to their house (Q7), the average of participants indicated 4 (SD = 1.54), which says that they think it is a bit important to see the entire street when exploring the changes to their house façade.

One important aspect for us to inquire was the level of wish to use this tool alone or together with a professional designer (Q8). Regarding this question, participants were divided. The average of participants indicated 3 (SD = 1.54), from which five indicated they would prefer or maybe prefer to use it alone and six indicated they would prefer or maybe preferred to use it with a professional.

We were also intrigued by what the inhabitants think concerning the level of control that should exist, or not, when altering houses in Malagueira. For that we asked if participants think that such a tool should control the changes to the houses (and therefore maintain the special character of the neighborhood) (Q9). The average of participants indicated 4.45 (SD = 1.29), which says that they think that the tool should exist and some of them highlighted that different features could be integrated. There was an outlier in the group of participants who responded with a 1 (meaning—"I think it should not exist"). This person was very concerned with what is going on with the "savage" customization in Malagueira.

Regarding what this tool could offer more (Q10), four participants said that the tool is good as it is now. Four other participants suggested that more options could be integrated in the customization options such as "the interior layout, furniture and color" and "options to paint the bottom line in the house when the street in not flat." The participant that indicated that the tool should not exist (in Q9) said the tool is good but fails since it presents solutions to inhabitants that are forbidden.

This last comment from one participant regarding the aspect of "forbidden" was often present in the conversations with inhabitants during the interviews. The tension within inhabitants regarding the possibility to alter the houses (mentioned by Mota [5] and Rodrigues [6]) was felt during the stage of attracting participants. Indeed, several inhabitants refused to talk when alterations in architecture were mentioned.

4 Discussion and Concluding Remarks

In this paper, we presented and assessed the MyChanges tool for visualizing architectonic modifications of existing housing in co-design projects with inhabitants that should enable the inhabitants to understand and explore alternatives for modifications of their housing. The paper focused on inhabitants of the Malagueira neighborhood in Évora, Portugal, and concerned their satisfaction with the tool and three possible interfaces to simulate alternatives of customization of their houses' façades. Interviews and tests were performed with inhabitants, and results show that a tool like MyChanges would have a good acceptance among inhabitants. We, however, note that the interviews and tests were done with 12 participants, which is a too small number for a quantitative and statistically significant analysis. Moreover, participants were chosen among the ones available in cafes and by appointment on the day of testing, which may have created bias since, e.g., inhabitants working outside the neighborhood were not part of the test. Hence, our results can at best allow a qualitative analysis of the acceptance of MyChanges.

4.1 Future Work

For future work, we envision enabling a direct customization while in the immersive virtual environment, not just viewing but also editing in VR with Oculus Rift and its controllers. Future work will also include the definition of a grammar that enables inhabitants in Malagueira to simulate the customization not only of the original façades, but also façades that are already customized and that the inhabitants wants to change. Such a tool involves a different approach in ICT development since it implies new features: (i) the recognition of the façade and its elements; (ii) the recognition of the already added elements to the façade; (iii) and diminished reality to hide what exists and is suggested to be removed.

Further work will also include interviews with architects about whether the modification design tool MyChanges can solve the task of finding a balance between customization modifications and saving the original architecture of housing, and about what improvements can be made to this tool for better solving this task.

4.2 Concluding Remarks

The MyChanges tool is meant as a way to respond to the issue that customization poses to architecture. It is aimed at supporting housing customization that accommodates the evolving needs of inhabitants. And it is aimed at supporting

customization that complies with the original architectural language of the housing by letting architects define the tool (the original architect, or others). Such tool can be used as a way of mediating the communication between architects and users in participatory design processes as advocated in the Open Building approach [10] and aiming at the users' acceptance. Also, the tool can be used as a way for users to express their wills by directly designing them in co-design processes as the ones explored in the U_CODE project.[9]

The research presented in this paper builds from Koolhaas' thoughts [3] related to the judgmental aspect of architecture regarding beauty by giving tools by which architects analyze and judge inhabitants' decisions on customizing their houses. This issue is then addressed by giving the inhabitants the power to co-determine changes to their housing in line with the "authorship" of architects.

By this solution, architects need to define identity-preserving refurbishment options for "context." For that the use of a shape grammar encoding transformation rules is a solution. Shape grammars are generative design tools that deliver customized design solutions based on the same principles of design for every single design problem. Since shape grammars uses languages of design, they force customization solutions to be in the language of design and therefore keeping the identity of the buildings.

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[9]See about the U_CODE (Urban Collective Design Environment) project here http://www.u-code.eu/.

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