Participatory Design Supported with Design System and Augmented Reality

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In this paper we present our research which is focused on developing and testing a method supporting participatory design process with a use of a design system and Augmented Reality interactive interface. We propose a concept of participatory design where participants can directly interact with architectural knowledge encapsulated in the design system. The proposed concept of participatory design supported with a design system was tested during a workshop conducted in Kaunas, Lithuania. The dedicated design system was created in order to minimize physical interaction between the architect and the users while allowing for customization of design solutions by participants. The design system and the participatory design process were linked with the use of a digital communication interface. The paper is concluded with a critical view on the process. The conclusions are based substantially on the results of a survey prepared by the authors and conducted among workshop’s participant.

Keywords: Augmented Reality, participatory design, design interface, parametric design

INTRODUCTION
Active involvement of future users in design processes is increasingly being introduced by architects to ensure that the design outcomes meet the users’ needs. Participatory design has been studied for decades, what results in the development of many collaborative design methods (Batchelor and Lewis 1985, Wates and Knevitt 1987, Zadow 1997, Kelbaugh 1997). The potential of augmenting these processes with the use of computer technologies was already foreseen over four decades ago (Cross and Maver 1973, Wrona 1981). The popularity of computer technologies allows architects to create their own design tools. Designers are now well equipped with tools to analyse the physical context of the project, but the ability to gather information about the social context is limited due to the lack of effective communication channels with future project users. The users can improve the final design by sharing their knowledge of the site along with their own needs and expectations for the project. On the other hand, the designer can support users by sharing his professional knowledge, experience in designing and proper execution of the final solution. Participatory design is a process where the user’s ex-
perience and the architect’s knowledge can be con-
fronted and merged in order to improve the design outcome.

A participatory design process requires efficient
channels of communication between the architect,
future project users and other stakeholders. The tra-
ditional process of direct discussion is limited by the
number of its possible participants. Therefore, in or-
der to implement participation with a wide public,
alternative communication channels have to be ex-
plored. Information technology offers new poten-
tials for citizen participation in urban planning such
as Augmented Reality (AR) (Hanzl 2007).

The use of AR in supporting public participation
has been attracting researchers’ attention for several
years. AR has been used in order to support par-
ticipation by visualizing the design proposals (Allen
et al. 2011, Olsson et al. 2012). While most of the
research is mainly focused on using AR to support
professional users in the design process (Fatah gen
Schieck et al. 2004, Belcher and Johnson 2008) there
is also interest in the research focused on support-
ing non-expert users in design participation (Cuper-
schmid et al. 2015).

In this paper, we present our research which is fo-
cused on developing and testing a method support-
ing participatory design process with a use of a de-
sign system and Augmented Reality interactive inter-
face. We propose a concept of participatory design
where participants can directly interact with architec-
tural knowledge encapsulated in the design system.
The dedicated design system is created in order to re-
pond to the identified design constraints, minimize
physical interaction between the architect and the
users while allowing for interaction with the prod-
ucts of formalized design rules and customization of
design solutions by participants. The design system
and the participatory design process are linked with
the use of a digital communication interface. In the
course of our research, we have developed a tangi-
ble tool a tangible augmented reality tool to support
multi-user participatory process.

PARTICIPATORY DESIGN SUPPORTED
WITH DESIGN SYSTEM

Algorithmic design methods allow formalization of
design principles used by the designer in a form of
an algorithm. A parametric description of the project
gives the designer a number of benefits, which in-
clude the possibility of exploring various design op-
tions, dynamic management of various design solu-
tions and automatization of the search for optimal solu-
tions. But algorithmic methods allow also to post-
pone the selection of final design solution, allowing
others to co-design in respect with formalized design
rules.

The ability to explore multiple design solutions
gives the opportunity to review them, verify and eval-
uate according to their individual properties. There-
fore, users interacting with a design system can learn,
in a practical way both the exposed architectural de-
sign knowledge and the limitations and possibilities
of an individual design solution. In this way, the users
are equipped with the knowledge to make an in-
formed decision based on the analysis of the advan-
tages and disadvantages of each solution.

The concept of participatory design supported
with design systems assumes that communication
between the designer and the potential user can take
place without direct dialogue between them. This
concept supports user’s own interaction with the de-
sign system as well as the interaction of multiple
users. In order to enable such interaction addition-
ally a digital communication medium is required.

Therefore the proposed concept consists of three
components (fig. 1) necessary for its proper applica-
tion. The design system and the participatory design
process are connected with a use of the digital com-
munication medium which allows the exchange of
information between them. All these elements are
interrelated and their proper interconnection is es-
sential for the effective application of the proposed
method.
THE EXPERIMENT

The proposed concept of participatory design supported with a design system was tested during a workshop conducted in Kaunas, Lithuania. Our ASK research team was commissioned to conduct a 5-day design workshop, which aim was to redesign Romuva Square by complementing it with a multifunctional urban bench. During the span of the workshop, organizers expected not only to create a design proposal but also to fabricate and assemble the designed object. The workshop participants were supposed to be, most of the city residents, who know the location of the project. Such conditions were a good opportunity to verify our concept of participatory design. The decision about the final shape of the design had to be postponed until the workshop was held in order to support it with a knowledge of potential users of Romuva Square. Additionally, the design system had to be developed beforehand in order to allow for fabrication of final object during a scheduled time of the workshop, while maintaining a high degree of possible modifications by workshop participants.

The aim of the experiment was to verify proposed concept of participatory design process supported with the developed design system and an interactive interface. Developed tool had to allow modifications of the design by the users and simultaneously visualize possible design solutions in real time. The visualization had to inform the discussion and choice of final designs in a multi-user environment. The digital medium of communication was intended to enable intuitive interaction with the developed design system and facilitate the search of the solution satisfying all workshop participants. The workshop's participants were supposed to jointly decide on the form, function and precise location of the proposed objects. Moreover, due to the tight schedule of the workshop, the participatory design experiment had to be conducted during only one day. Additionally, the developed tool was supposed not only to support the design process but also to guarantee the realization of the design in a scheduled time. The main aim of the planned experiment was to validate usability of the developed tools in a participatory design process and to test it in the real case scenario.
PARAMETRIC DESIGN SYSTEM

The form of the bench was designed in a parametric environment, Grasshopper, that allows controlling the object’s parameters at any stage of the design process. The intention of the design was to allow the participants to modify the layout of the bench and to control the detailed parameters of its transverse shape (fig. 2). The bench layout has been determined based on the location of physical objects, placed on a printed map of the location. The objects corresponded to control points that, when meeting some distance criteria, connected in order to form a bench segment.

Manipulated control points were divided into three types, which determined the shape of the cross section of the bench and thus its function. Each of the cross-section types was assigned a range of influence that controlled at what distance the points formed a connection between them (fig. 3).

If the distance between the two control points was less than the sum of their range values, the connection between the points was generated. Changing the ranges of the influence of each control point in relation to each other or all simultaneously influenced the scale and proportions of the generated object.

The developed design system assumed the possibility of selecting and changing the profile type, on the individual segments of the bench, by the participants in the design process. For this purpose, we have developed 3 different seating profiles whose design principles have been formalized using parametric design tools. In this way, different sections of the bench can be assigned a different function, such as the seat with the backrest, deck chair as well as support for the standing person. In addition, the parametric design rules of each of the transverse sections allowed for the detailed modification of its form by the participants of the experiment. In this way, we not only allowed the ability of users to select the function of the selected section of the bench but also to modify the detailed parameters of the sections to suit their individual design expectations (fig. 4).
DIGITAL COMMUNICATION INTERFACE
In order to enable testing of different spatial layouts of possible design solutions in relation to their direct surrounding and to enable rapid information exchange between the participants of the design process, we created a dedicated, Augmented Reality-based, interface.

The decision to implement Augmented Reality comes from research conducted by Markusiewicz (2016). The technology seems to be at least partially solving issues with ‘traditional’ human-computer communication based on a mouse, a keyboard and a screen. Viewing digital objects in three dimensions using a mobile device work through direct manipulation of the virtual camera through device movements - as if one had a video camera in their hands. Implementing AR also allows for targeting multiple senses when communicating information and thus increasing the effectiveness of a message. The use of AR-based tools in architectural participatory design does not require users to have a high level of technological familiarity to understand its purpose and utility (Cuperschmid et al. 2015).

Another sense that provides immersive interaction with a computer is touch. Research conducted by Kim and Maher reveals that tangible user interfaces positively change designers’ spatial cognition, and then these affect the design processes by increasing designers’ problem-finding behaviors (Maher and Kim 2006).

Following Billinghurst’s classification of augmented realities, we decided to combine AR-based visualisation with tangible interaction in order to provide an immersive experience: by extending physical models and combining access to digital information with intuitive physical-model interaction.

The hardware setup (fig. 5) of the interface consists of:

- Augmented Reality tracker: a printed panel being a graphical representation of the site plan that at the same time determines the workspace.
- Control blocks: nine digitally augmented physical elements of three different types. They represent control points that the participants distribute on the workspace. Different types stand for different sections of the bench: a bench without backrest, a section with backrest, a barrier - a vertical element without a place to seat.
- A video camera placed above the workspace responsible for transmitting the image of the distribution of the control points to a dedicated software.
- Mobile devices equipped with a custom application for visualizing the generated form in real time using Augmented Reality.

Three main software solutions are used to synchronize users’ actions and interface elements:

1. reacTIVision - an open-source framework developed by Martin Kaltenbrunner and Ross Bencina for image recognition in the project ‘Reactable’ (Jordá et al. 2005) - is responsible for interpreting the image from the camera and mapping the position and rotation of each of control blocks. It passes the information about their coordinates to a Grasshopper definition using UDP protocol.
2. Grasshopper definition - developed by the authors. The position and orientation of control blocks serve as input for the algorithm generating the geometry of the bench. Each pair of control points placed close to each other is converted into a bench segment through lofting the section curves assigned to each type of control blocks. The resulting geometry is represented by a polygonal mesh. The information about the mesh is converted into a text message consisting of a list of vertex coordinates and sequences of vertex indices that form its faces. The message is passed to the next software using UDP protocol.
3. AR-based application - developed by the authors in Unity using Vuforia plugin to implement Augmented Reality. The application
runs on mobile devices. It constantly receives information about the geometry of the bench in form of a text message generated by the GH definition. It decodes the message to generate a mesh representation of the bench that can be rendered in real-time using Unity’s rendering engine. By recognizing the AR tracker, it virtually places the geometry on the site as viewed by the user of the mobile device.

The way users work with the dedicated interface is a recursive process. It starts with distributing control blocks on the AR tracker. The information is captured by the camera, decoded by reactTIVision and passed the Grasshopper definition that generates the geometry and sends all the necessary information to mobile devices that the users constantly hold during the procedure. The application on the devices renders the mesh superpositioned on the tracker so that any user is able to verify their actions and introduce changes by altering positions of the control blocks (fig. 6). The whole process is relatively fast (10 - 500 ms depending on the complexity of the geometry and the number of mobile devices used simultaneously) and allows for real-time verification of actions. Multiple users may interact with the interface to create one digital model that is rendered on all the mobile devices.
PARTICIPATORY DESIGN PROCESS

The workshop participants mostly were architects or students of architecture. Therefore, in order to mimic participatory design process participants were divided into groups. Every group was assigned a task to represent one or two of the identified social groups of potential users of the square. We planned the participatory design process to be conducted in three stages: analysis, designing with a use of developed interactive interface and choice of the final project. The first two stages were conducted by every group individually while during the last stage all the groups were confronted.

During the analytical stage, every group was supposed to carry out their own study of the project site context in order to define the main design assumptions. They conducted their own functional-spatial analysis, including analysis of the form and scale of the architectural elements of the square, analysis of terrain, human movement and visibility. Additionally, in order to set their design goals, we asked every group to define the needs of the social groups they were representing. This knowledge allowed them to prepare conceptual drafts of the square improvements while still not being aware of the possibilities and limitations of the interactive design interface they were going to use in the next stage.

Upon completion of the analytical stage, every group had an opportunity to use the dedicated interface to visualize their design. During 60-minute design sessions, members of each group tried to either recreate their own design concepts or create new designs based on the developed ideas (fig. 7). In both strategies, initial design ideas had to be confronted with the capabilities and limitations of our tools. At the time of this design phase, every group was able to create several design solutions and compare them. At the end of this stage, each group had to choose the best, in their opinion, solution that meets the needs of the user group they represent.

In the last stage, all workshop participants had to decide on the final design to be fabricated. During this stage, every group had to present their final concept explaining main design ideas. These presentations were supplemented with AR visualization of the design using the same interactive tool that was used for designing. After the presentation of each of the groups, the other participants were given the opportunity to ask questions and discuss together the proposed solution.

After listening to five presentations and analyzing design proposals in augmented reality, all workshop participants selected two design solutions through voting. The final design solution was chosen after a discussion where the disadvantages and advantages of both solutions were pointed out. These
arguments convinced the authors of the chosen solution to make further improvements. Among others, at the request of the workshop organizer, the selected project was reduced in size to allow its fabrication within the time constraints. All changes were made only by the authors, and the effect of the changes was visualized in real time to all participants. As a result of the planned process, a compromise solution was developed which was accepted by all participants and fabricated during the rest time of the workshop (fig. 8).

EVALUATION OF THE EXPERIMENT
In order to evaluate the experiment, participants were asked to complete the evaluation questionnaires at the end of the workshop. The questionnaire consisted of 34 questions and 13 out of 17 experiment participants filled out the survey. Among the people who completed the questionnaire were representatives of all focus groups. Most of the workshop participants (92.3%) were practicing architects, but more than half of the respondents declared that it was difficult for them to take on the role of future users. At the same time, most people felt engaged in group work and indicated that they had an impact on group design proposal.

The survey showed that not all participants in the experiment managed to obtain a design solution that they sketched. Almost 54% of the participants failed to obtain their preliminary design solution using the dedicated interface. At the same time, 11 out of 13 participants (84.6%) were satisfied with the final solution achieved by their group. All the respondents indicated that the proposed tool helped their group in choosing a design solution.

The responses in the survey confirmed the observations made during the experiment that the choice of the final design solution was difficult for the majority of the participants and that the chosen solution was a compromise. Only one person indicated that he/she was very satisfied with the chosen solution while 7 people were rather satisfied.

The questionnaire also included open questions. The workshop participants were asked to indicate what was lacking in the participatory process. Among the given answers, two dominant groups of comments can be distinguished. Firstly, the participants thought there were too many design constraints. Secondly, there was a general opinion that the time dedicated to the design and selection process was too short.

The survey also included questions about the intuitiveness of the developed tool. For most workshop participants, a printout of the map representing the site was intuitive. For the majority of users, physical interaction with markers that modify the shape of the bench was rather intuitive and changing the shape of the bench by changing the location of the markers was intuitive. But 4 people indicated that modifying the bench section by rotating the physical marker was counterintuitive. Nevertheless, the majority of respondents stated that making changes using physical elements while observing the effects of these changes on mobile devices was easy.

CONCLUSIONS
The conducted experiment fulfilled its objectives and assumptions. All the scheduled research tasks were successfully completed within the set timeframe. Computer-aided design participation was also successfully conducted. During one day the participants were able to find a shared design solution that was
a compromise between different expectations of five groups representing distinct social groups. The workshop allowed to simulate the conditions of a real project in which a computer-aided participatory design process could be used.

In our opinion, the effectiveness of computer-aided participatory design process was partly due to the initial limitation of possible design solutions. The limitations were introduced in the proposed design system by its designers. The authors of the design system consciously - based on their own analyses and imposed time-technological constraints - decided to limit possible design solutions to the various forms of space arrangement using the object of the bench. Such decision allowed to reduce the discussion on alternative and detailed solutions while giving the opportunity to focus on selected topics. The discussion about the final design was limited to problems issued for modification by the workshop participants.

As the surveys showed, the participants noticed many design constraints that limited the ability to obtain their pre-developed design concepts. It should be noted that all the participants in the experiment were professionally trained architects or architectural students. Most likely, on a daily basis, they are designing while being exposed to a variety of digital and non-digital design tools expanding design capabilities. The analytical phase, which concluded with design sketches, has awakened the design expectations of the workshop participants. However, in the stage, they were confronted with the possibilities offered by the tool. Additionally, the requirement of voting for only one final solution was limiting the expectations.

However, dynamic discussion accompanying the choice of the final solution was effectively supported by the developed tool. The possibility of modifying the designs in real time, verifying the obtained solutions with personal design assumptions and verifying the results in relation to the environment allowed the participants to carry out a substantial design discussion supported by visualized solutions. In addition, the proposed tool allowed to multiply the number of project iterations and accelerate the design process by avoiding manual modeling and visualizations. The proposed design and visualization method was so convincing that the participants at final stages of design process modified designs without looking at the visualization by simply moving the physical markers on the map (fig. 9).

For most participants, the process of choosing the final solution was a difficult task, which ended in the choice of a compromise solution. The process ended with a very different degree of satisfaction for each participant. This may indicate that the participants were very much attached to their individual design ideas, which they found hard to abandon in favor of a solution proposed by another group. Therefore, it seems necessary to continue the experimental research, with a focus on conducting it with non-designers, representatives of the various social groups using selected space.
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