From Shaping to Information Modeling in Architectural Education: Implementation of Augmented Reality Technology in Computer-Aided Modeling

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While learning computer-aided modeling techniques, students of architecture should not only gain knowledge on how to model three-dimensional forms, but also how to define and understand the information beneath the shapes. Architectural presentation as an intellectual communication-focused process requires new media to channel information in a contemporary way. These can be text, image, sound, video or a digital model. The integration of augmented reality in teaching computer-aided modeling in architecture school provides more thorough learning experience as it opens new opportunities. The authors present the process of implementing AR technology in architectural education - its theoretical background, the outcome of students' work and technical solutions. They argue that the use of AR interface increases the effectiveness of user-model interaction in comparison to standard mouse-based techniques of three-dimensional manipulation due to the intuitive touch-screen interaction and direct control on the camera.

Keywords: Augmented Reality, Computer-aided Modeling, Unity 3D

INTRODUCTION

The physical elements of a building's structure, theoretical concepts being the outcome of functional, ergonomic or financial constrains, as well as historical and cultural context all form a unique characteristic of an architectural project. A model representing the project should focus on information. Thus, while learning computer-aided modeling techniques, students of architecture not only should gain knowledge on how to model three-dimensional forms, but also how to define and understand the information beneath the shapes.

The integration of augmented reality (AR) in teaching computer-aided modeling in architecture school provides more thorough learning experience as it opens new opportunities such as interaction, access to video and sound data and the possibility of organizing content in a multilayer layout. This implies the necessity to master multiple skills: advanced knowledge of architectural modeling using BIM tools and/or freeform surface modeling software, management of data concerning specific project, tools of communication between the author and the observer. All of these are crucial for future architects.

In this paper, the authors describe the process of implementation of AR technology in architectural ed-
ucation using the example of the course of modeling held in the Faculty of Architecture at Warsaw University of Technology in academic years 2013/2014 and 2014/2015. The authors describe the theoretical and academic background of the process, the outcome of students' work that involves augmented reality, the technical solutions that have been applied and the educational significance of the course.

ARCHITECTURAL REPRESENTATION
The way one perceives and understands their surrounding affects one's needs and their fulfillment. Architects traditionally represent reality with sketches, technical and perspective drawings, physical and digital models. By using these means of representation, they create images of their work. Processing these images helps predicting the results of future materialization. The conceptual model and the final result are not identical in architectural practice both in conceptual stage (verification of ideas) and in phase of construction (issuing of instructions). The understanding of architecture is conceived due to the interpretation of sensory impulses - mainly due to visual perception. One acquires information by analyzing optical effects, tactile and acoustic sensations and past experiences. The language of architectural representation reduces collected data to compact message. By sketching and creating models, architects create hierarchies of their observations and possible solutions. Geometry - as mathematical means for 3d space interpretation - is essential in achieving understandable representation. (Słyk 2012)

Thales introduced geometrical concepts such as line, point, angle, as well as theorems on relations between objects, similarity and proportions. The system built on his thoughts led Euclid to formulate 'Elements' - the base for geometrical research until 18th century and Giovanni Girolamo Saccheri's 'Euclides ab omni nævo vindicatus'.

The works on perspective of Ambroggio Lorenzetti, Filippo Brunelleschi and Piero della Francesca as well as the science of optics investigated by Alhazen, Witelon and later by Simon Stevin and Johannes Kepler, gave us the ability to represent three-dimensional objects with drawings. Thanks to 17th century works of René Descartes the theory of space and the theory of numbers could be combined in a coordinate system. Algebraic description of geometry opened the possibility to computational management of objects and transformations in 20th century.

The year 1963 and Ivan Sutherland's Sketchpad was a breakthrough for architectural drawing. The first computer-based design tools were a digital version of a 19th century drawing board they replaced. Later, they evolved to advanced dynamic databases, supporting building information management, its process of construction and lifecycle. Today's tools provide users with shaping, analyzing and editing architectural creations based on digital models.

Antonino Saggio defines architecture as dual: consisting of objective and subjective space. The first is strictly based on materiality and measurements. The latter involves individual perception (Saggio 2010). Jan Słyk points out that a model (or hypermodel) and instruments of perception (that can be amplified through interaction and affecting multiple senses in an innovative way due to technology) are instruments sufficient for understanding architecture (Słyk 2012).

COURSE OF MODELING
The subject of the course "Computer-Aided Modeling" held in the Department of Architecture is to create models of historical and modern examples of projects that had major contribution to the architecture of single-family houses. These models have three main objectives in the process of architectural education. Firstly, they are tools to learn computer aided modeling. Secondly, they allow students to better understand building components such as walls, slabs, columns etc., which is crucial at the early stage of architectural studies. Finally, during the modeling process, the students gather information on the modeled building and thus gain knowledge on the structural, functional and aesthetic solutions implemented in acclaimed examples.
During the course the students are involved in three major stages of using information technology in architecture: (1) information modeling, (2) parameterization and (3) communication.

At the beginning of the course, the students acquire the necessary information about each building and transform it into a digital model. The geometry of the model is complemented with data about the specific context. This data varies from structural solutions, to materiality, function and spatial solutions, to historical background or building’s relation to the surrounding. This information can be defined as attributes inside of BIM program, additional 3d form, schematics or text message.

After the initial modeling stage, parameters changing the perception of the model may be introduced. Every building has elements that can be affected by variables. It this stage we focus especially on the examples that are modular, parametrically generated or contain kinetic elements. These examples can be defined with scripts or parametric models. Other examples can be altered through different means in form of interactive presentations revealing various aspects of the project, videos showing the construction process or structural simulations.

At the end, a message for potential spectator is defined in form of a presentation. The constraint is a static printed panel on which the work has to be presented. This often results to be an insufficient medium to effectively present the work when confronted with a digital model enhanced with additional media.

The message resulting from the modeling process is supposed to meet the criteria of a new medium as described by Lev Manovich, i.e. numerical representation, modularity, automation, variability and transcoding (Manovich 2002). Implementation of augmented reality gives the students the opportunity to show their work in a more flexible way, whereas the spectators are provided with a more understandable presentation.
The text accessible through augmented reality application can either provide users with extra information or it can become a hypertext allowing access to external resources such as online repository of information on the model or its particular component. The presentation of Urbanowicz-Muszyński twin house in Warsaw by Bohdan Pniewski is complemented with fragments of a critical article on the building from 1936 'Arkady' written by Edgar Norwirth. The spectator chooses between the analytical description provided by students and historical opinions.

Images or series of images provide better understanding of the modeled object by e.g. showing historical evolution of the surrounding area or focusing on real-life details that were not included in the model itself. The panel presenting students' work on the Farnsworth House by Mies van der Rohe is an example of a virtual presentation consisting of text and images organized in different layers that are only accessible via augmented reality technology. The printed panel itself contains abstract graphics and when browsed with an AR application it is supplemented with visualizations and description in two alternative organizations. [Fig. 1 and 2]

Sound is often used either to strengthen users' perception or as a more artistic impression. It can also provide access to a musical piece that was an inspiration to the architectural form. The Philips Pavilion by Le Corbusier became a motivation to create a Grasshopper definition for parametric generation of geometrical forms based on rhythm, scale and length of a musical composition. The students based their creations on two musical pieces that can be accessed through QR codes that are placed on the panel.

Videos combine the assets specific to both image and sound resulting to be useful when presenting the work through a flythrough animation, physical simulation of kinetic elements or a more personal, graphical analysis of the project. Students modeling Shigeru Ban's Curtain Wall House performed physics-based simulation of the curtain's behavior with Grasshopper and Kangaroo Physics. The simula-
tion was recorded as an animation and rendered on top of a printed still frame extracted from the video. Viewing the printed panel through an AR application gives the impression of motion of a static printed element [Fig. 3]. Another interesting example of video usage was an artistic impression on Le Corbusier's Heidi Weber Pavilion. It is an animated decomposition of the building's elements and its conversion to a planar colorful composition. [Fig. 4]

An interactive model accessible through augmented reality allows free and intuitive perception from different angles and distances and can be easily altered by turning on and off particular layers of information, such as architectural elements (external walls, roof) or hierarchical organization (floors, functions). One example is a digital model of Jacobus Johannes Pieter Oud's Weissenhof Row Houses that can be customized by a spectator. By touching the screen of a handheld device, one browses through a sequence of different layers of the model: (i) the whole row of houses with closest surrounding, (ii) one module separated from the context or (iii) the module with external walls turned off to show the interior [Fig. 5]. Another example is Frank Lloyd Wright's Fallingwater, where the user can decide which floor to turn on or off to better understand the complexity of the function. [Fig. 6]

The model can be further supplemented with other media, such as sound or text rendered when zoomed on a point of interest. In Czesław Przybylek's Willa Julisins model one can hear piano music when zooming a handheld device on the living room, which focuses on its main function via the sense of hearing. In Wright's Robie House the viewer gains access to hyperlinks containing more specific information when zoomed on a piece of furniture. Such digital augmentation constitutes the multilayer typology of a hypermodel. It may emphasize certain characteristics of the project the model represents and enhance its perception by affecting determined senses.

APPLICATION INTERFACE
At the early stage of implementing augmented reality in the course of modeling in the academic year 2013/2014, a set of freeware computational tools was used as addition to the standard modeling software taught during classes. Metaio Creator was used as a tool for converting planar graphics to AR trackers and supplementing them with digital content with an easy-to-use drag-and-drop interface that does not require programming. Final setups were published with Metaio Cloud and could be accessed via QR codes with a free mobile application Junaio.

In the academic year 2014/2015 the solution described above was replaced with a custom AR application. The reason was to ensure bigger flexibility in programming particular application features, provide access to augmented content without the use of QR codes and become more independent from third-party software.

The first version of the application was created by Jacek Markusiewicz using a game development platform - Unity 3d with Vuforia extension providing assets and SDK for augmented reality implementation. Digital models exported from McNeel's Rhinoceros3d as Wavefront .obj or .3ds files are imported as assets to the Unity project and assigned to corresponding trackers, that are abstract graph-
ics designed for the application’s purposes. The behavior of virtual camera is established by Vuforia plugin. Interaction is defined with C Sharp scripting language in Unity's MonoDevelop IDE. The platform allows the usage of materials and effects rendered in real time. It also facilitates compiling the final application for a specified platform.

The AR application provides the students and spectators with intuitive touch-screen interaction and simplifies model browsing by giving them direct control on the camera. This type of interface seems to be increasing the effectiveness of user-content interaction in comparison to standard mouse-based techniques of three-dimensional manipulation. In the authors' opinion, hardware aspects of human-computer interaction is the field of computer-aided modeling that needs most of attention when contrasted with highly advanced modeling and analysis software that users nowadays have access to. The way users edit and browse three-dimensional content with a mouse, a keyboard and a screen is underdeveloped - its effectiveness and intuitiveness can and should be improved.

One of the reasons to that is what Slyk calls a double projection effect. Standard computer mouse navigation is by definition two-dimensional. Thus, all three-dimensional operations such as zooming, panning and orbiting have to be projected from the three-dimensional imagination of the user onto a two-dimensional plane on which a mouse can operate. The actions performed with a mouse have to be then processed by software and applied in three-dimensional coordinate system. (Slyk 2012)
What we define as three-dimensional navigation in software, in real life is a simple and intuitive action, where looking at an object from different distances and different angles does not require intellectual effort and consists of moving and rotating either one's head or the object they perceive. However, translating such movements and rotations (of either a virtual camera or a three-dimensional object) into mouse operations results in mathematically complex transformations that have to be defined by the user. In other words, in real life one's brain performs inverse kinematics transformations that meet our needs, whereas while using computer software, one needs to perform forward kinematics transformations in order to achieve the desired effect.

The double projection and the forward kinematics manipulation may lead to imprecision, latency and, what is most important, the shift of user's focus from the content to tool management.

Even though human-computer interaction experts such as Jef Raskin and Bruce Tognazzini question the existence of fully intuitive interfaces (Raskin 1994, Tognazzini 1992), research shows that many types of interaction such as tangible user interfaces positively affect the efficiency, cognitive processes and three-dimensional abstraction of a user (Kim and Maher 2006, Sharlin 2004 after Abdelmohsen and Yi-Luen Do 2007). Augmented reality seems to be at least partially solving navigation issues as looking and perceiving is intuitive and follows the inverse kinematics mechanism: pointing a handheld device camera on a virtual object visible on the screen is directly understood as camera transformation.

CONCLUSIONS AND FUTURE APPLICATIONS
Architectural presentation is an intellectual process that focuses on communication. The use of augmented reality can channel a message through multiple senses and provide interaction between the receiver and the medium of communication. The students that employ augmented content in their presentations tend to use different means of expression than the ones that present their work in a traditional way. The printed panels of the first are more schematic and contain less explicit information while the digital content accessible through a mobile application is complete.

Moreover, the possibility of including media such as video and sound, otherwise impossible, en-
courages students to do so, resulting in more time spent on creative work during the semester. Such workflow is exceptionally well received by the students, which is reflected in the results of a survey conducted amongst 66 course participants in June 2014. Course's scientific and educational content was graded 4.71/5 (4.25 being the average score of all courses held at the faculty), didactical skills of the tutor were also graded 4.71 (4.17), tutor’s attitude towards students 4.79 (4.40), technical conditions and equipment 4.61 (3.97) and formal aspects such as grading criteria: 4.76 (4.20). Finally, the students evaluated their own involvement as 4.5/5, being higher than usual (4.13).

AR-based presentations also seem to affect the way spectators explore architectural models. Content of such presentations is not directly accessible but requires exploration. Due to its hierarchical organization, some additional information has to be searched for by either zooming on specific elements or triggering an event with for instance a touch. This provides an element of mystery and surprise and leads the spectator to think they are playing a game - which results in their greater immersion. (Caillois 2001)

Further development in applying augmented reality in architectural education is planned. The course of modeling shows that both students and spectators respond positively to working with architectural model through this technology. Its intuitive interaction and efficient navigation can be further investigated in applications that not only allow users to perceive architectural content but also alter it by reorganizing, customizing and finally modeling architectural or urban elements. Although it still seems unlikely to create a fully functional architectural or free form modeling software based on augmented reality, the authors want to introduce elements of AR-aided interactive modeling in the future courses to explore the possibilities of facilitating architect-computer interaction.

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