AUGMENTED REALITY DESIGN DECISION SUPPORT ENGINE FOR THE EARLY BUILDING DESIGN STAGE

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Abstract. Augmented reality has come a long way and experienced a paradigm shift in 1999 when the ARToolKit was released as open source. The nature of interaction between the physical world and the virtual-world has changed forever. Fortunately for the AECO industry, the transition from traditional Computer Aided Design to virtual building design phrased as Building Information Modeling has created a tremendous potential to adopt Augmented Reality. The presented research is situated in the early design stage of project inception and focuses on supporting informed collective decision-making, characterized by a dynamic back and forth analytical process generating large amounts of data. Facilitation aspects, such as data-collection, storage and access to enable comparability and evaluation are crucial for collective decision-making. The current research has addressed these aspects by means of data accessibility, visualization and presentation. At the core of the project is a custom developed Augmented Reality framework that enables data interaction within the design model. In order to serve as a collaborative decision support engine, the framework also allows multiple models and their datasets to be displayed and exercised simultaneously. The paper demonstrates in the case study the successful application of the AR tool during collaborative design decision meetings.

Keywords. Augmented Reality; Design Decision Support; Data Visualization.
1. Introduction

Augmented reality has come a long way since Heilig’s (1962) Sensorama and Sutherland’s (1968) “Sword of Damocles”. Since its initial science heavy origin, running on heavy and expensive hardware and equipped with complicated software, the field of Augmented Reality has experienced a paradigm shift in 1999 with Kato’s (1999) release of the ARToolKit to the open source community. The nature of interaction between the real-world with the virtual-worlds has changed forever. Especially for scientific researchers around the world it became an ecosystem of bidirectional information flow. New ways of augmenting reality with virtual means are being developed (Samsung Gear VR, 2014) on a rapid paste and soon is going to reach the consumer goods market.

Fortunately for the architecture, engineering, construction, and facility operations (AECO) industry, the transition from traditional Computer Aided Design (CAD) to virtual building design phrased as Building Information Modelling (BIM) (Eastman et al, 1974), has created a tremendous potential to adopt Augmented Reality in many stages of the design process, from inception and concept design to design development and construction.

The presented research is situated in the early design stage of inception and concept, supporting the cognitive processes exhibited during the collective decision making process (Reason, 1990). From a sustainable point of view, this stage contains the most potential to achieve an increase in building quality and cost savings in the long run (WBDG, 2014). This early stage is characterized by a dynamic back and forth process between an array of spatial, environmental or economic analysis, and massing studies and form finding. These analytical processes generate a large number of data during their iterations that have to be collected and stored initially, and later accessed, compared and evaluated. The trained eye exhibits rapid evaluation of resulting data and thus the interactive and visual approach based on AR has been chosen. Therefore the focus of the current research is on data accessibility, visualization and presentation. At the core of the research is a custom developed java based Augmented Reality framework that has been optimized for performance to enable seamless accessibility. During the computational process the model’s context and analysis’ geometry of each iteration is stored as lightweight vertex buffer objects. By means of a custom developed OpenGL based viewer, these objects are displayed in a user-controlled manner via a flexible User Interface (UI) class. The core engine allows for instant and seamless navigation through the various iteration models as well as user-defined dynamic 3D cut section views. In order to serve as a collaborative decision support engine, the framework also is capable to display hundreds...
of geometrical complex models at once. This creates a superimposed picture of all provided options, enabling intuitive evaluation of all model spaces. A special feature of this engine is its capability of visualizing analysis data also individually or in an upper and lower bound range that enables goal-oriented search for specific data within the 3D space. The paper demonstrates on a case study the successful implementation of the AR tool placed with physical context during collaborative design decision meetings.

2. Research Background

2.1. DESIGN STAGES AND CHALLENGES

Since 1963 RIBA has organized the architectural design and construction process into the “RIBA Plan of Work” (RIBA, 2014); a standardized framework that is publicly available. The goal is to provide clearly defined stages and responsibilities that reflect the actual process as well as the organizational structure that exercises these processes.

With the increase of computational support for design the amount and nature of data potentially available to improve design decisions has challenged the industry in respect of the actual ability to exercise, evaluate and use these data. In recent years new technologies and processes, such as BIM have disrupted the AECO industry due to its integrated design approach (Gu, 2014) that suggests a Lean BIM process (Krakhofer, 2012) towards better performing buildings. The integrated approach implies that more information has to be processed early on in the design stage. This puts pressure not only on the design team, but also challenges the “Plan of Work” in respect of fee structure, contracts and responsibilities. As a result the time needed for analysis, evaluation and transformation becomes critical.

2.2. DESIGN DECISION SUPPORT SYSTEMS

During the DDSS Conference in Eindhoven in 2006 (Van Leeuwen, 2006; Timmermans, 2006) several novel approaches toward Design Decision Support Systems have been presented. Especially relevant to the current research are Activity-based models, Micro-Simulation Models, and Virtual Environments. It has been concluded that design teams frequently struggle to acquire and visualize data about their projects, most noticeable during the early phase of design. There is an increased demand on rapid data collection and creation, as well as accessibility and exercisability. As the common denominator, visual conversation has been identified to play a significant role during the cognitive processes of collective decision-making. It is argued that the negotiation between digital and physical data navigation and representation currently presents a bottleneck for further improvements. The presented
research has investigated the three fundamental components of a DSS, such as knowledge base, model and user interface. Interactivity has been highlighted as the key towards effective data visualization and exploration for improving DSSs in collaborative settings.

2.3. AUGMENTED PARAMETRICS
In order to be able to use the presented analytical tools effectively, they are developed to become part of a novel CAD framework called “Augmented Parametrics” (Kaftan, 2014). The purpose of the system is to find the best optimal solution to a given architectural problem. Its framework simplifies parametric modelling while maintaining high level of building data in order to quickly and precisely calculate building’s analysis. The system expands the contemporary parametric systems by embedding bi-directional solving algorithms and multiple simulation modules.

The system is subdivided into three main parts:
1. Building component data
A data system collects geometry as well as building information such as material, wall-type, etc and parses a database of building elements.
2. Analysis
The simulation components are built around highly efficient algorithms that allow real-time computation. The development focuses primarily on the analysis of building energy consumption, daylight, cost and structural efficiency.
3. Cognitive system control (CSC)
The CSC contains single and multi-criteria algorithms. It also contains an interactive interface for the user to steer and control the optimisation process.

![Figure 1. Simplified framework of “Augmented Parametrics”](image-url)
2.4. NEW MEDIA IN DESIGN - AUGMENTED REALITY

In “Framing Mixed Realities”, Schnabel (2009) has outlined the effects of new Reality Technologies on the ACE industry. Technologies that merge real-life situations with computer generated visual information create a combined virtual and real space (Anders, 2003).

In “Business Insight Using Visualization at Boeing” Kasik (2011) describes visualization as the “broadest channel to the human brain”. As soon information is displayed visually within the context, abstractions are reduced. Analysis Data, represented visually are most suitable for visual evaluation and Augmented Reality is targeting this aspect of communicating information contextually and interactively. With the increase of computer power and improved algorithms, the gap between digital and physical is shrinking. In recent years, an increased amount of research into augmenting reality with digital means has resulted in a technology that is now entering the mainstream market. AR tools such as AR-media (AR-Media 2014) can be connected to standard design software, such as 3dsMax (Autodesk 2014), etc. AR is being used in many fields, such as the car-industry, home appliance industry, and home furnishing industry, etc. in order to interactively engage consumers. Due to the availability of smart phones and their built in cameras, more advanced apps will be developed to merge the virtual with the real in an augmented fashion.

2.5. WORKFLOW AND DATA COMMUNICATION

“RIBA Plan of Work” provides a good overview about the workflow during the design process. However with the adoption of BIM and the integrated approach to design, the traditional plan of work has experienced mutations. Due to the increased amount of data necessary for evaluation early on in the design, the method of communication has changed significantly. Two-dimensional snapshots of analysis results have been replaced by three-dimensional analysis results and they in turn are being replaced by four-dimensional simulation of analysis results. The new dimension will be the interactive and contextual analysis in real-time. From the perspective of exercisability, these changes have created a gap in the evaluation process. Tools provided by the major software vendors, such as Autodesk, Bentley or Graphisoft provide analysis functionality within their platform. This works well, but limits accessibility and exercisability for project members who don’t have the software or don’t know how to use the software. There is currently no commercial tool available to the industry that supports rapid interactive and collaborative data visualization for exploration.
3. Case Study

3.1. COMPUTATIONAL CONCEPT AND WORKFLOW

Analytical simulations have become standard procedures that guide the design process, due to its potential of rapid feedback based on its visual representation. These simulations tend to generate a large quantity of information that can fall in the range of gigabytes and thus attract attention for exercisability. The designers need to be able to sort, visualize and navigate intuitively through this information to accelerate communication and decision-making. The underlying concept is multi-fold.

The choice of developing a stand-alone tool rather than a plugin for existing software lies in the need to be lightweight, independent and free of licensing restrictions in order to be accessible for every project partner.

The most basic functionality is rapid exchange between analysis, CAD and AR Tool. Therefore the OBJ format was chosen, because it presents a commonly used file format in the CAD field that contains geometry and other values.

In order to enable intuitive navigation, the AR approach was chosen, because it enables navigation with the user’s own hands, holding the marker if necessary. Placing the marker into a context model or the actual space is also possible. Hands-on navigation also enables collaborative discussion making and exploration, due to its easy accessibility via the marker and a platform independent App.

The intuitive exploration of data is of outmost importance and thus all geometry that contains a value can be displayed. Additionally a range-selection of values is necessary to accommodate the user’s exploration strategy of lower bound, upper bound or custom selection.

The basic workflow used in practice is enabled, starting with exporting from the analysis tool or CAD to the AR Tool via OBJ files for collaborative viewing and exploration. After the specific data set is identified and collectively agreed on, the selection can be exported as OBJ-files into the CAD software, the design team is working with. Each team member can then respond to the analysis geometry explicitly.

3.2. APPROACH

In order to allow for an open source software development, the chosen platform is the java based processing.org (Reas, Fry, 2007) environment combined with the integrated development environment Eclipse (Eclipse, 2014).

For each step of analysis, the geometries are stored in standard OBJ (Bourke, 2014) format and a correlating MTL (Bourke, 2014) format that holds visual (material) properties. There may be more optimal formats for
data storage in terms of loading speed, but the OBJ format is supported by a prevailing number of CAD programs.

The navigator parses OBJ files and creates Indexed-Face-Set (Rikk, Bell, 1997) structure of data. All the structure is further stored in a memory buffer (VBO) and stored on the GPU. Once loaded, instantaneous viewing of very large amount of geometry is possible. The OpenGL functionality also enables dynamic clipping of parts of the model.

For rapid navigation, the NyARToolKit (NyARToolKit, 2014) and video camera for 2D marker tracking system was utilized. The NyARToolKit is based on the original ARToolKit (ARToolKit, 2014), but written in java for optimized ease of portability across different platforms and operating systems. The NyARToolKit can interpret the angles, axis and location from the two-dimensional markers, scale and place the model correctly onto the marker.

The basic functionality implemented at this stage is Model selection, dynamic clipping planes in x/y/z, and range data selection. Dynamic clipping planes and range data selection can interactively be controlled by the user via the user interface. The user interface is located on the top left of the screen and made as intuitive and interactive as possible, using a slider system. The tool automatically checks the model for the min and max values and sets the slider upper and lower bound. This applies to the analysis values as well as the model dimension and thus, the same function can be applied to clipping planes and range data selection.

The model clipping planes allow a detailed exploration of specific areas within the model. For example, the user can clip in “Z” to only display the figure ground, or clip in “X” to display only one elevation of the model, etc.

The range data selection presents the total range for one analysis. However for exploring the values, a custom range functionality was added that enables the on-screen selection of a specific single value, as well as a specific value range. For example, the total value range is 100, the specific value is 46 and the specific value range is plus/minus 5. The user can move a single slider to see the values from (41(46)51) and can move then up (7(12)17) or down (78(83)88), etc.

3.3. APPLICATION

The AR Tool has been applied to an urban analysis project in Hong Kong, in a small neighborhood called Sau Wah Fong in Wan Chai. Due to its success the project was chosen to be exhibited at the UABB Bi-City Biennale of Urbanism / Architecture Hong Kong 2013 (Krakhofer, 2013). The site was chosen for its pedestrianized nature. The project team aimed to analyze the
area for its human comfort that includes diffuse light, direct light, visibility, as well as proximity to the built environment.

The team has generated a 3D context model based on the Hong Kong Digital Map. The context model’s surfaces were gridded based on a three-dimensional grid with the edge length of one meter. By means of a custom developed analysis framework, multiple data sets are generated and exported as OBJ files. Each data set is based on the same grid. The gridding functionality is in essence a scaling function that can dynamically be adjusted in different stages of the design. In the early design stage when rapid feedback for refinement is needed, the analysis time needs to be kept short and thus a slightly larger grid size will be chosen. For more detailed analysis results a finer grid size has to be chosen. The decision of grid-size is crucial and has to be carefully identified by an experienced analyst.

All geometry is exported as OBJ files and correlating MTL files and are labeled with the “type”, “_” and ”Serial number” (Vis_1.obj Vis_1.mtl).

All provided geometry is loaded as OBJ files and stored in the “data” folder that is accessed by the AR Tool. After all elements are loaded the AR Tool accesses the data and creates the data-sliders.

The NyARToolkit and camera function will detect the marker when fully visible in the camera viewer and projects the geometry onto the marker. Loading the geometry may take at startup, about 90 seconds for 16 million triangles.

Thereafter all geometry in the different models can be accessed and exercised using the sliders. When the agreed data set is defined, the geometry can be exported and loaded into the CAD package for further refinement.

Figure 2. AR Tool: UI, Marker, proximity analysis, visibility analysis.

3.4. EXERCISABILITY

Licensing free access and portability is fundamental to exercisability. The user interaction is based on only two tasks, hand-movement and slider-
movement. The user interface is kept simple and easy to learn, also for non-proficient computer users. A hand held camera and the marker are for navigation. The user interface, based on sliders is for data exploration.

The navigator function is the core to enable rapid exercisability. Based on the lightweight index-face-set generated by the OBJ file, all data are stored in the memory buffer (VBO) of the GPU. As soon the data are loaded they can instantaneously be viewed; even very large amount of geometry.

The chosen graphics standard OpenGL (OpenGL, 2014) functionality enables dynamic clipping of parts of the model and thus has been adopted for x/y/z clipping planes.

The fact that multiple people can access the marker with their hands makes this tool highly interactive and exercisable for rapid and informed decision-making.

4. Conclusion

This early exercise into custom developed AR Tools for early comparative and collective decision-making focused on exercisability within the architect’s workflow.

During the integrated design approach, a parallel evaluation of different types of analysis has to be conducted in order to achieve a holistic solution for the project. While developing the AR Tool, it was noticed that commonly available analysis tools do rarely allow the export of their results in a specific file format that contains geometry and analysis data. As a result a separate research into an open source analysis platform has emerged that will be discussed in a different paper. The provided OBJ and MTL format has proven to be robust and exchangeable between AR Tool and CAD platforms.

The choice of processing.org has been proven to be very successful and suitable for rapid development and testing. Its java-based nature supports the future server-based development.

Navigation using AR has tremendously eased the accessibility and enhanced exercisability. Its intuitive hand motion approach has created a very natural and active discussion while exploring the data rapidly.

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