Tangible mixed reality on-site

Interactive augmented visualisations from architectural working models in urban design

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Abstract. The consequences of architectural planning and design decisions made in the early design phases are hard to foresee. While professionals are used to reading plans and understanding architectural models, most laypeople are not familiar with their abstractions. This can lead to misinterpretations and misunderstandings between the different participants in the design process, especially in complex building situations, and decisions can be made or rejected that can have far-reaching consequences for the remainder of the project.

In this paper we describe the concept and prototypical implementation of a decision-support system for the early design and discussion stages of urban design projects that aims address precisely this problem. The setup directly connects physical volumetric models and hand-drawn sketches with an interactive, mixed-reality visualization presented on a tablet or mobile phone, making it possible to see an interactive real-time view of an architectural design within the context of the actual site. In addition, the system is able to incorporate interactive simulations conducted on the model and presented in the AR-view.

Keywords: early design stages, urban design, HCI, tangible interfaces, immersive environment, simulations

1 Problem

During the early design phases presentations and discussions between architects and clients usually involve sketches, paper and models. While designers are used to working intuitively with these tools, laypeople are not used to reading plans or scale models and find it difficult to relate these abstract representations to the real world. Many people, therefore, find it hard to assess the impact of design decisions at this stage for the later result.

An alternative means of presentation is the use of perspective drawings and visualisations that show how an architectural design will look in a real scenario or the actual con-

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text. With the availability of affordable and ever more powerful computers, hand-drawn perspectives have mostly been replaced by digital visualisations, initially in the form of individual rendered images and more recently in the form of immersive and interactive environments such as Augmented Reality or Virtual Reality presentations. A key problem in this context is the fact that sufficiently detailed computer models take time to construct and are therefore costly to produce. In addition, in the early design phases, the design idea is typically in a state of flux with many unknowns. At this stage such presentation methods are therefore only really suitable for presenting and choosing between pre-prepared versions and variants. While these offer a certain degree of choice, new ideas that arise during discussions with the users and clients cannot be visualised on the spot. These methods do not, therefore, support a true exchange and collaborative exploration of ideas.

With the increasing complexity and size of modern building tasks comes a concomitant rise in the amount of information that informs a design project. To stay on top of this, digital analyses and simulations are increasingly being used to verify the feasibility of design decisions. The information that needs to be communicated increases along with the complexity of their internal interrelationships. As these become harder to understand, the more reliant we will become on using digital media to present, communicate and discuss ideas.

The fundamental problem therefore can be traced to a discrepancy between the different presentational media. Hand-drawn sketches and models make it possible to work interactively and to explore and discuss ideas in real time, but they contain a reduced set of information. Digital models make it possible to present complex analyses and simulations but, due to inadequate interfaces on the one hand and their complex preparation requirements on the other, are only partially suitable for interactive use. We are not, therefore, exploiting the full potential of digital tools.

2 Approach

Given the problem of this discrepancy between established design tools and digital presentation media, we need to find new approaches that make it possible to also communicate complex interdependencies to the viewer in a comprehensible way. In addition, we need to progress beyond the current rigid methods to facilitate a direct and intuitive way of working with the design idea. Only then will it be possible to directly develop and interactively present design ideas for all participants whether experts or laypeople. In this paper we describe a method for interactively presenting architectural ideas in an AR context using established design tools such as hand sketches and models. This approach gives rise to a totally new interactive presentation and discussion platform that bridges the gap between established design methods and mixed-reality architectural presentation techniques. The primary objectives are to find a simple, intuitive and direct means of input and to simultaneously make it possible to see the presentation of the design changes in real time in an immersive context and a real environment. To achieve this, the test platform creates a direct connection between physical volumetric models and hand-sketches, and an interactive, mixed-reality visualisation presented on a tablet or mobile phone. This makes it possible to see an interactive view of architectural design ideas at the actual building site.

Over the past few years as part of the research project "CDP / Collaborative Design Platform", we have developed a concept and a prototype for a design platform based on an analysis of the design process and the identification of the key requirements of a design tool [1-3]. A central feature of this self-developed and self-built hardware and software setup is the seamless coupling of established design tools, such as a working model and hand-drawn sketches, with interactive, digitally computed analyses and simulations, and interactive presentation methods. This seamless, real-time connection between the physical working model and hand-drawn sketches eliminates the need for complex modelling activities: changes in the physical models (position, shape) or in the hand-drawn sketches are digitally reconstructed in real time and interactively displayed in a mixed-reality view. While the architect can design using familiar tools and methods, the observer has an entirely new mode of viewing. Different ideas and scenarios can be tested spontaneously and new ideas can be developed and viewed directly in three dimensions on site. This not only promotes dialogue and design exploration between professionals, but also helps non-professionals participate as they see the results simultaneously presented virtually but within in a tangible environment. The client is involved more directly in the process and can contribute own ideas and changes, and then see these presented on the fly in 3D on the real building site.

The ability to also present interactive analyses and simulations, both in the model as well as in the AR-view, makes it possible to provide additional information for decision-making and augments the physical tools with digital data. This makes it possible to assess the further implications of an architectural design decision directly on site by providing additional objective parameters for consideration. As such, decisions are not made purely on the basis of subjective criteria but are backed up by real-time analyses and simulations, such as overshadowing, energy efficiency calculations, or noise impact simulations presented interactively within the actual context. This information, which would normally only be available at a later stage in the design process, can therefore be accessed much earlier, and can inform design decisions and creative deliberations in the early design phases by providing objective data to support decision-making. Design participants and decision makers can therefore make more informed decisions in the early design and planning stages.

2.1 User scenario

Using the setup described above, we can describe a typical use case for this concept as follows. The design task is the development of a master plan for an urban design project. The client and developer meet with the architects and representatives from the local planning authority on site to discuss a number of aspects ranging from cost minimisation to factors such as the shadows the buildings cast and the build up of traffic noise. Instead of poring over 2D printouts of plans and an accompanying model, the participants have several tablets and a multi-touch environment with automatic real-time 3D object recognition.

The multi-touch table shows the as yet unbuilt site plan of the building site, on top of which lie physical blocks of styrofoam (XPS: extruded polystyrene foam) cut to size to show an initial design for the arrangement of the urban blocks. The table display shows the results of a noise impact simulation, with critical areas highlighted. On the tablets, the users can also see the design proposal as an augmented reality visualisation superimposed onto the real environment. Here too, the viewer can see the results of the noise impact simulation.

The lead architect explains the design idea to all present making use of the model and simulations. As he describes specific aspects, he alters the arrangement, adding, removing or shifting blocks around the model to illustrate how he or she arrived at the current design. The digital simulation adapts immediately to reflect the different situations. The arrangement of the physical blocks is reflected in the display on the tablets, and the noise impact simulations is re-calculated and displayed both within the model as well as on the tablets.

Fig. 1. Using an AR app, users can experience the design scenario immersively and view it in the context of its real surroundings. The scenario itself is modelled using a physical model and hand-sketching on a multi-touch table and then computed for display in real time on a mobile device. Simulations can be displayed in the app, adding an additional layer of digital information to the modelled scene and providing additional objective information for more informed decision-making.

When the architect is finished, the client responds with questions of his own regarding the placement of certain buildings and suggests a position for the company's high-rise headquarters. He takes a new larger block of Styrofoam, trims it to size and places it at the corresponding location. The building volume is immediately recalculated and redisplayed in the AR-view on the tablets. The perspective view of the simulation shows that the height of the new building impacts on its neighbours. The overshadowing simulation also shows in numbers that the potential solar gain of the neighbouring buildings would fall by around 40% annually. The combination of the view in perspective, backed up by the numerical analysis of the design implications convinces the client that this option brings disadvantages, and the group then discuss among themselves how the different interests could be reconciled.

2.2 Related work

In 2013, Chi et al. [4] presented “Research trends and opportunities of augmented reality applications in architecture, engineering, and construction”. Two aspects of this paper are relevant in our context: on the one side these are digitally-supported design tools. On the other side it discusses tools for Augmented Reality presentation using virtual geometries on site.

Augmenting additional information such as simulations and analyses directly in a physical model can be seen in URP [5] and the project Tangible 3D tabletops [6]. Projects that employ purely virtual models include “The Augmented Round Table” [7] and the project by Seichter and Schnabel [8]. Using a Head-Mounted Display, a virtual scene of a digital tabletop model can be viewed and edited by several different users as a means of improving communication and collaboration. Another approach in this vein is sketchand+ [9] in which a real, physical model of the surroundings serves as the basis for the scene. Using a Head-Mounted Display in combination with markers located in the real model where the design is to be inserted, virtual design variants can be viewed directly within the scene. By switching different markers, one can compare different design variants within the physical model. The projects mentioned here offer the possibility of examining and discussing urban designs in a model view but do not show it within its real context. Välkkynen et al. [10] presented a project that aims to address this. The paper describes a concept for a “Mixed Reality Tools to Support Citizen Participation in Urban Planning” comprising a system that “includes a tangible tabletop interface combined with 3D printing and on-location AR visualizations” [10]. Using 3D printed tokens, insertions such as noise-protection barriers can be placed within an interactive map. The AR app shows a mixed-reality view of the building site. The authors hope to incorporate a feedback function such as the possibility to make comments and to include questionnaires in a future development of the project. While the authors describe a concept, they do no elaborate on the approaches and description of its technical realization. The inclusion of the models as 3D printed objects in the creative process is also disruptive to the designer’s flow of thinking between visualising and analysis.

In 2009 Wagner et al. [11] showed an approach for supporting social collaboration processes in an urban design context. As part of the project “Urban Planning in the MR-Tent”, an interactive environment was developed in prototypical form for use in public participation procedures. The on-site setup included a multi-touch table and two large projection screens that showed a superimposed live image of the building site. Tokens placed on the table represented objects in the mixed-reality scene and could be positioned and controlled. The tokens were linked via so-called content cards with the virtual objects (3D volumes, simulations or similar), making it possible to communicate flexibly with them. This approach does make it possible to flexibly re-assign the purpose of the tokens, but the system still requires pre-defined elements. The Urban Sketcher [12] project is also worth mentioning in this context. The tool is a mixed reality application for improving communications between project participants in the urban planning phases. Urban Sketcher makes it possible to sketch interactively within a mixed reality view directly on the building site. The physical setup in both projects uses a wired webcam and the projection method limits freedom of movement and only allows the scene to be seen from a single viewpoint.

The project by Allen et al. [13] is interesting from the public participation viewpoint. Using a mobile AR app, different design variants can be viewed on site. The interface provides a means of assessing different variants. However, these have to be modelled in advance and anchored within the system, and it is not possible to make changes to them while viewing. As such it is not suitable for use in creative thinking and design processes.

Wang et al. [14] have investigated on-site information systems for activities at the construction site and for discussing rationales. Among others aspects, the authors describe a requirement for interdependency between different roles of participating individuals and the need for a link between paper, whether digital or traditional, and the physical situation. Their work focuses more on on-site project progress monitoring and controlling than on real-time design. With their proposed setup, markers also need to be added to the environment.

Kwon et al. [15] investigated the development of a defect management system that provides on-site visualisation on tablet devices. Their system requires the users to place fiducial markers in the environment to facilitate registration of the visual content. Registration with the markers needs to be undertaken manually and it seems that there is no network interconnection to disseminate data online.

Zollmann et al. [16] built a tool for construction sites to support monitoring and documentation by incorporating aerial snapshots. Their work focuses primarily on data capturing and 3D reconstruction. It investigates dedicated visualisation techniques for information on the progress of the built structure. Aerial photos are taken with a drone and are transmitted to a 3D reconstruction client which then provides a 3D model of the differently timed states of the construction process for on-site visualisation. The on-site visualisation can then be used for surveying tasks, such as measuring the dimensions and sizes of objects and for annotating information.

The work by Sørensen [17] aims to improve communication of construction and maintenance plans for large-scale buildings and uses on-site AR in the form of AR binoculars with built-in position and orientation trackers. The system is portable but not meant for completely free movement. Because the position is fixed at any one time, the system need only continuously measure orientation. The system provides robust precision data and therefore reduces accuracy problems for distant objects.

3 System setup

To realise our proposed concept, we use a combination of hardware and software. Both aspects need to be considered in order to build an integrated system. The system setup consists of two linked areas – the Collaborative Design Platform (CDP) (Fig. 2, left) and the on-site AR application (Fig. 2, right):

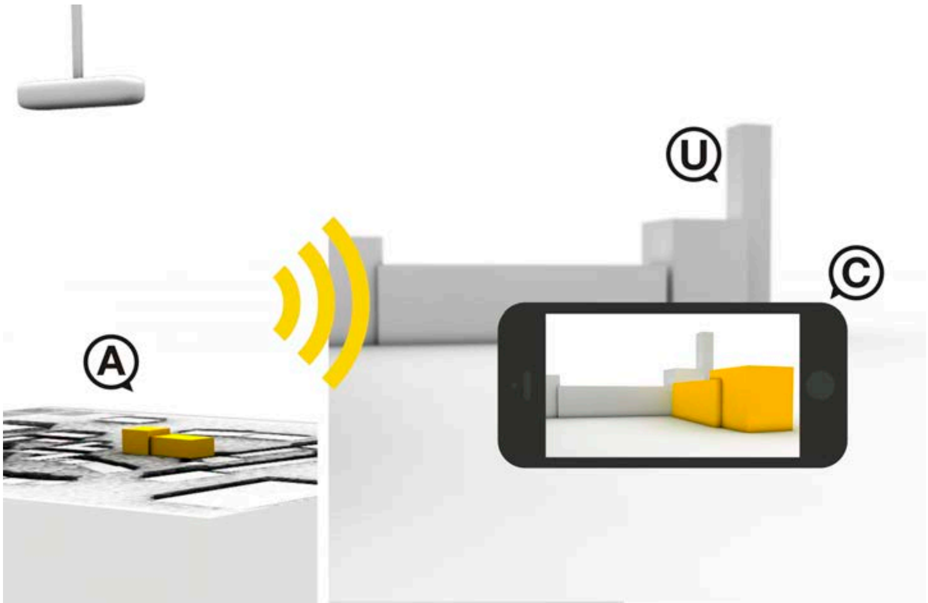

Fig. 2. System setup showing both parts of the system: the design-platform (left) and the on-site AR application (right). A network protocol links the physical model placed on a display of the design environment (A) with the display on the mobile device (C) in real time. The real environment (U) is augmented with the design model, providing the viewer looking at – or rather "through" – the mobile device with an immersive view of the design proposal on location in its actual context.

- **Collaborative Design platform (section 4):** The first component of the system setup is an interactive design environment in the form of a real-time interface between established design tools, such as a working model and hand sketches, and digital tools, such as analyses and simulations [1-2]. The context of this example is the early design phases of an urban design project at a scale of 1:500.
- **On-site AR application (section 5):** The second component of the project described in this paper is the mobile Augmented Reality application. The application is a bipolar network protocol operating in real time with the design environment. This link makes it possible to use mobile devices to view the design scenario as it stands in the physical model as a mixed-reality view in the context of the actual environment.

The real-time link-up between these two parts of the system makes it is possible to offer an entirely new form of interactive presentation. The following section describes each of the system components in greater detail.

4 CDP / Collaborative Design Platform

The technological basis of the Collaborative Design Platform (CDP) is a large-format multi-touch table with real-time 3D object recognition [18]. This system obviates the needs for markers in the physical model, making it possible to flexibly and freely alter the model as desired and to have these changes reflected immediately in the digital reconstruction.

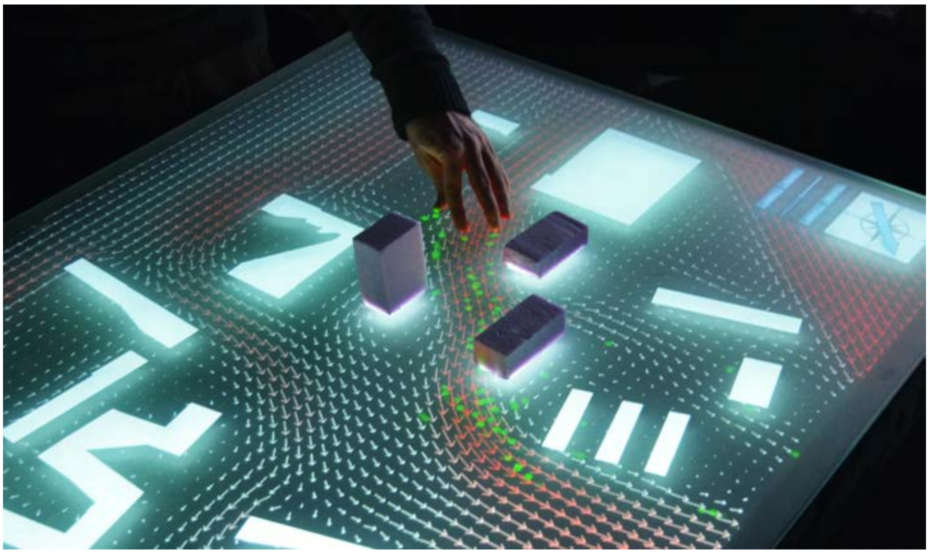

Fig. 3. Interactive simulations (e.g. a wind simulation) are produced in real time in response to changes made to the three-dimensional physical model. The system requires no markers, making it possible to model flexibly and freely when exploring a design idea.

An additional vertical touch screen serves as an info panel and can be used to sketch interactively into the perspective scene of the design scenario [19]. The physical model and digital sketch are seamlessly linked. If the physical model is altered, the virtual scene, including any hand-sketches, analyses and simulations, updates to match it. This makes it possible to work very flexibly with different kinds of tools and information.

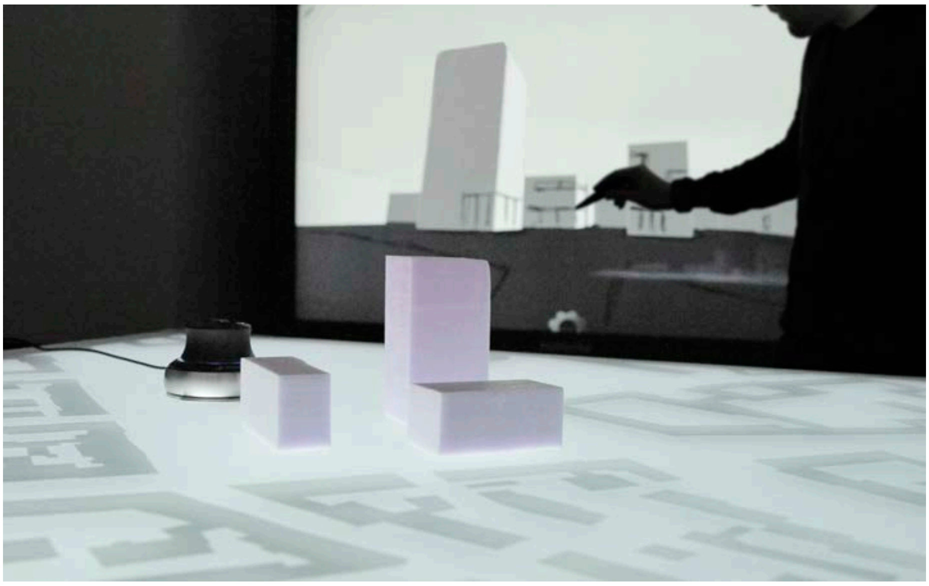

Fig. 4. An additional vertically mounted touch screen makes it possible to sketch interactively in the perspective view.

The software setup uses a plugin-oriented software architecture that comprises two components:

- The middleware, programmed in C++, which serves as the basis for processing the system-relevant basic functions such as 3D object reconstruction, tracking, data basis, output on the different screens, recording of data including versioning, and so on. Semantic GIS data served as the basic underlying plan for the map, providing not only geographical position data but also additional information of use for the analyses and simulation. The positioning in the coordinate system is on the basis of worldwide referenced spatial data.
- The second component comprises the plugins, written in C#. This principle enables different design-support tools, such as digitally computed analyses and simulations, to be attached flexibly to the middleware for use in the system. It also allows the system to be extended to meet specific needs so that it can be tailored to different building tasks and their respective requirements.

This setup makes it possible to develop new modules for calculating overshadowing or wind simulation and to incorporate these flexibly into the system. All of these respond to the data transmitted from the design environment with the arrangement of the physical model on the multi-touch table, adapting interactively and in real time to the new situation, and therefore to the momentary expression of the idea of the designer.

To be able to effectively compare different variants, the software prototype for the design platform supports versioning, making it possible to recall different prior states of the design. The software uses GIT as its concurrent versioning system. The geometric data of the reconstructed physical working model is stored as .ifc files. Different variants are shown as a timeline in a tree structure and each separate state is marked with a timestamp and screenshot as versioning attributes.

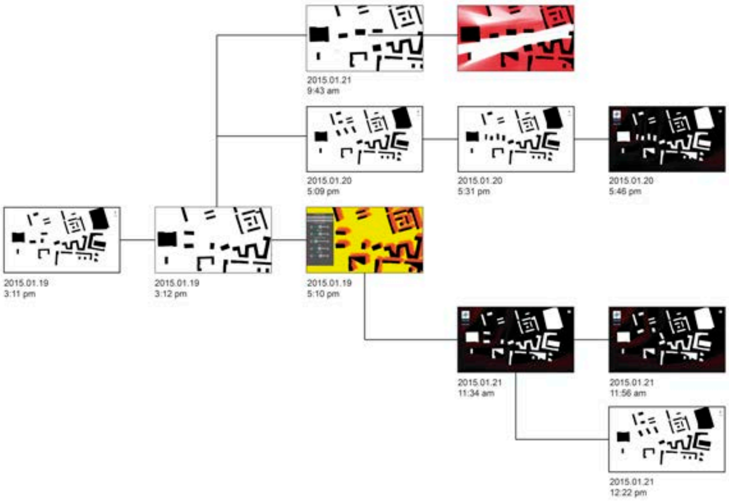

Fig. 5. Screenshot of the design platform. Different versions in a tree structure sorted by time.

The flexible concept of the platform also makes it possible to extend the scenario as required. The interaction method is achieved using a flexibly deployable TCP/UDP-protocol that makes it possible to establish a two-way platform ⇔ device connection [20].

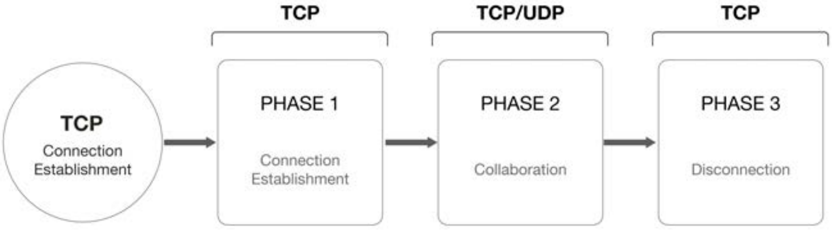

Fig. 6. Overview of the connection phases [20]

In this way, the digitized design geometries based on the physical models and sketches are provided for further applications, such as the in this paper described AR-application. In addition to the reconstructed models and sketches, the geometry of the surrounded buildings, as well, as the semantic data based on the underlying GIS-model, are also provided via the protocol.

5 On-site AR application

As part of the sub-project described in this paper, the Collaborative Design Platform (CDP) has been extended with a concept for and prototypical implementation of an interactive AR app. The AR app makes it possible to interactively view an architectural design elaborated in the form of a physical model as a virtual representation in its real intended context.

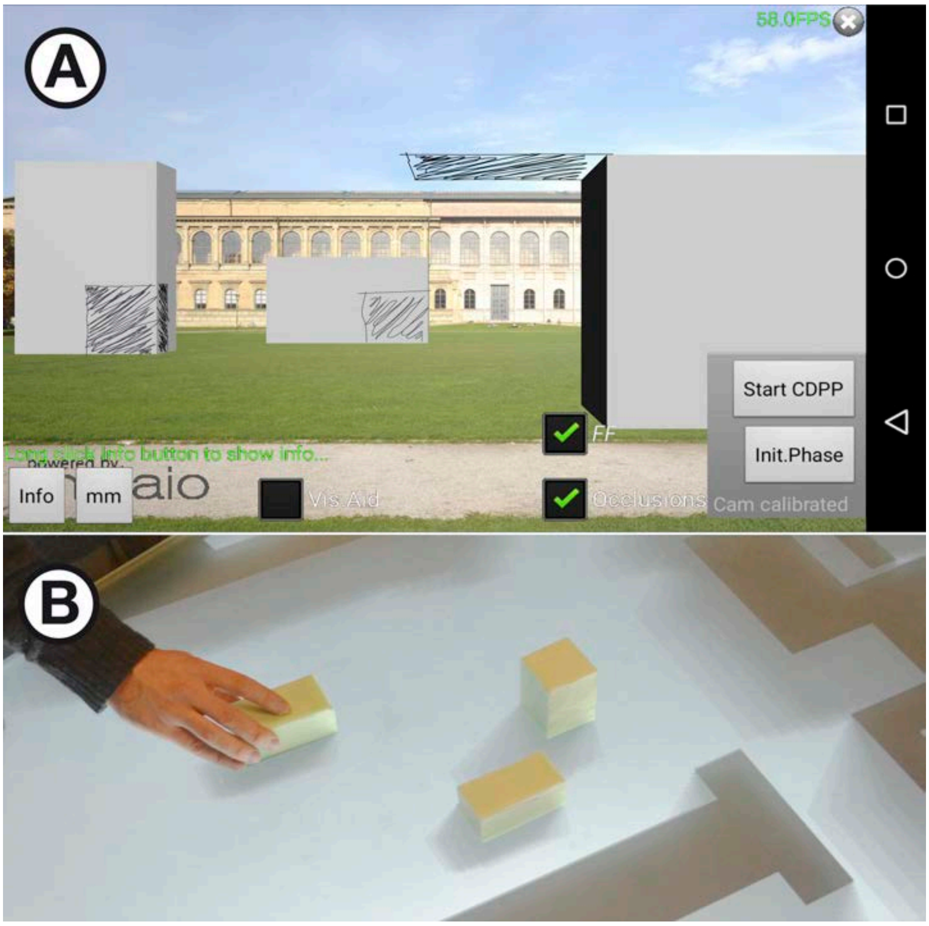

Fig. 7. Screenshot of the mobile application (A): The reconstructed geometry of the physical objects on the multi-touch table (B) is shown directly in its actual environment as a mixed-reality view on a mobile device (A).

To implement the concept, it needs to fulfil the following requirements:

- Use a physical model or hand-drawn sketch as input device
- Transfer of data provided by the design platform in real time
- Ability to recall previously saved design variants
- Ability to track in the AR app without using markers
- Presentation of simulation data to assist decision-makers

5.1 On-site setup

The on-site visualisation tool is implemented as an Android application that acts as a new client connecting to the server. The connection can use either WiFi or a mobile network. The user selects an architectural sketch to show from a menu list and can choose from previous versions and variants of a design, or apply a real time visualisation of the physical model on the design platform plus any hand sketches augmented onto the physical working models. After selecting the desired scenario, the camera of the hand-held device is activated and the camera picture is shown on the screen.

On logging in to the server, the protocol transports building data (reconstructed from the physical working models as well as from the GIS data) and data about any currently existing hand sketches augmented to the physical models (see fig. 4). Since the Android application uses another rendering system (Metaio SDK [21] instead of OpenSG [22], which is used in the design laboratory), the data is converted to be handled appropriately. After login and transfer of the current lab state, each successive change (modification of the sketch or physical model) is sent to the clients instantaneously. The scene is rendered on-screen, superimposing the camera picture and using the correct perspective of the hand-held Android device with respect to the spatial position and orientation within the environment, a facility provided by the tracking system of the Metaio SDK.

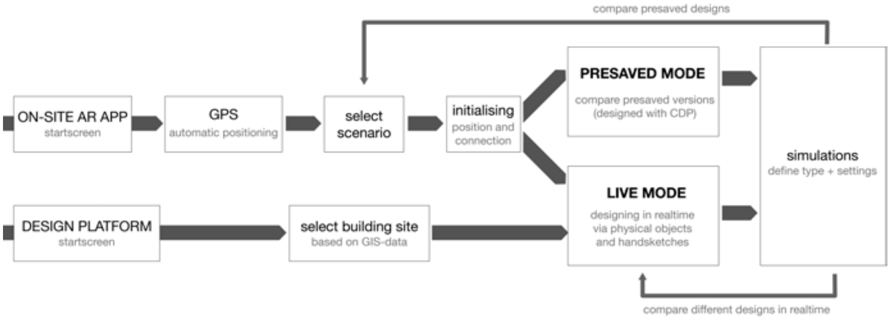

Fig. 8. Information flow interaction between system and user

5.2 Tracking

The coarse positioning of the viewer's device is based on the GPS-position in combination with the, via the protocol transmitted geo-coordinates of the building site. Since GPS only provides positional data and because the precision of this data is insufficient for the accurate placement of AR visualisations, other methods need to be used. Even the integration of the device’s in-built compass and inertia devices would not provide sufficient accuracy.

The AR rendering system therefore relies on optical feature tracking. After assessing different available solutions, the Metaio SDK was selected. It provides facilities for two methods of initialisation and subsequent tracking.

To initialise the estimation of the correct pose (position and orientation), a line model of a neighbouring building (or another arbitrary object) is required which can be mapped to the edges found in the camera picture of the Android device. This replaces the need to place additional markers in the environment. The line model is shown on the screen of the hand-held device and the user must move the device so that the line approximately aligns with its physical counterpart in the vicinity. The line model can be scaled and rotated via touch gestures so that it aligns with the real building. Once the alignment is sufficiently near to the actual situation, the system automatically snaps the line model to the detected edges of the physical building and starts tracking.

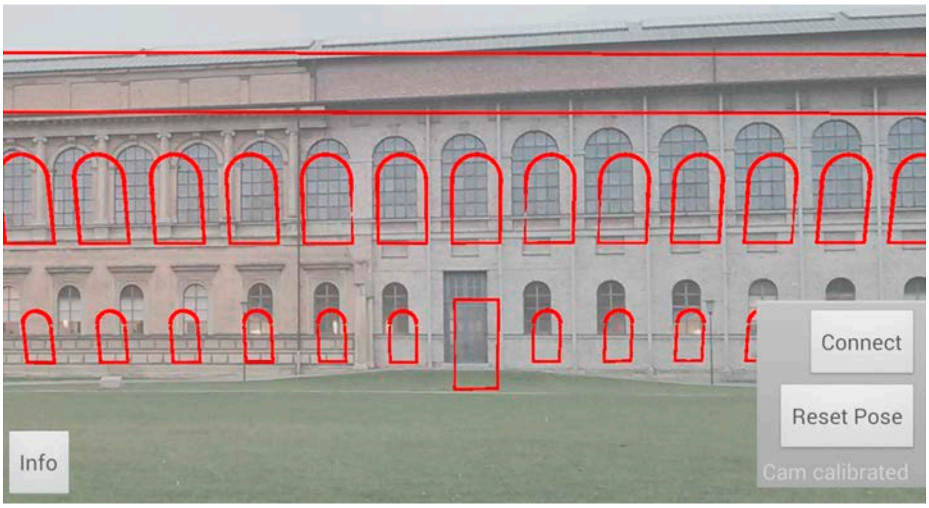

Fig. 9. Initialisation phase: the line model is matched to the features that are found in the camera picture.

Tracking is then handled using natural features found in the camera picture. The Metaio SDK stores these feature points internally and generates a 3D world map that remains active even if one turns around so that none of the initial features are visible in the camera view. To tracking the system requires features that can be detected and stored. A white wall, for instance, would not provide any natural features and tracking would have no reference points to follow. While tracking is operating, the system calculates the position and orientation of the hand-held device and feeds this data into the rendering system so that the architectural sketches are superimposed and correctly aligned to the camera picture. To define the area where the features should be created and tracked, a surface model of the environment needs to be provided. Assuming that the geolocation of the line model is known, a future version of the application could return the estimated position and orientation of the device, in turn giving the table user visual feedback on the outdoor user's location and viewing direction on the digital map on the multi-touch table. This would allow collaborators to have a better understanding of what they are discussing during a session.

Fig. 10. Due to the image feature tracking, it is possible to walk through the scenario. As long as the tracked element is in sight, the object are displayed on real position.

5.3 Occlusion handling

As the virtual content is simply rendered on top of the camera image, occlusions can be incorrect when a physical structure is nearer to the viewer than the computer-generated sketch. The virtual sketch then incorrectly overlays the physical object.
The surface model of the environment, based on the data of the surrounded buildings provided via the TCP/UDP protocol, can be used to remedy this occlusion problem. This surface model is invisibly added to scene rendering and prevents the parts of the sketch that would not be seen from being rendered.

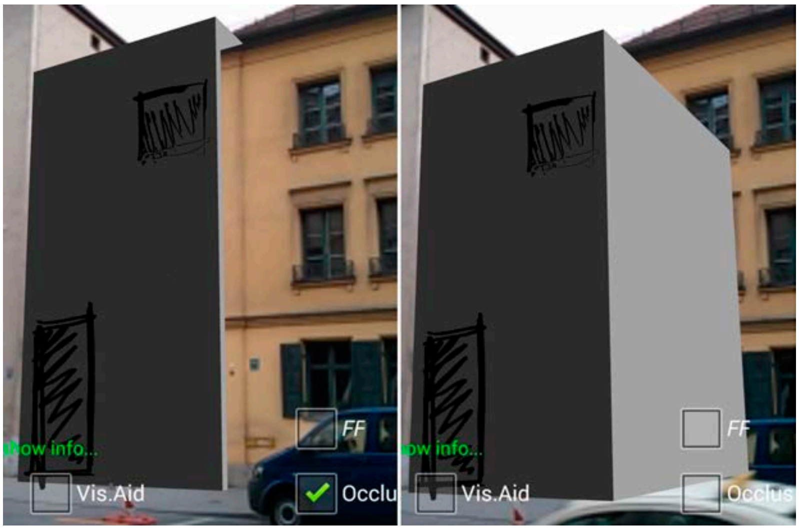

Fig. 11. Screenshot of the app showing occlusion-handling activated and deactivated

Occlusion problems can, however, still arise with physical objects that are not part of the surface model. For example, the surface model typically includes building structures but not trees, bushes or passing cars and pedestrians. These cannot be rendered into or out of the scene.

Ongoing research in the fields of computer vision and rendering is, however, in the process of trying to identify the distance of objects from the viewer, and can already provide a degree of full occlusion handling. As yet, these aspects have not been integrated in the demonstration prototype.

5.4 Simulations

As hand-held devices have a touch panel and motion sensing, they provide a means for the user to interact with the scene. One example of such interaction exploits the potential to add simulations to the scene by simulating the passage of the sun. The user could activate a computer-generated sun that illuminates the scene with a correctly placed light source. The user can then see how the sun illuminates the planned building. The incident sunlight simulation can respond to the respective geolocation, orientation and time of day. A fast forward mode allows the user to gain an impression of sunlight incidence over the course of a day.

Fig. 12. Screenshot of the sun-simulation: course of a day.

5.5 Implementation

The prototype was developed for Android smartphones and tablets. The main part, including the interactive GUI, is therefore written in Java, while all the network communication with the design-platform runs using native C++ routines, to facilitate the ease of maintenance of the protocol that also runs at the table. The natively running part of the application asynchronously communicates all events received from the architects working on the model to the user interface without interrupting real-time rendering. Java Native Interface JNI bridges between Java and C++ code.

An event triggered by an action at the table is transmitted as a message via the provided protocol (see section 4). Messages that transport data on buildings or sketches contain lists of three-dimensional vertices and how they are interconnected. The mobile application receives these lists and uses them to generate a file in a format that can be interpreted by the rendering engine. Rotations and translations of existing buildings are simply applied to the respective virtual object.

To achieve maximum flexibility, the application was tested with and adapted for display on devices of different sizes from 4.7" to 12.2" and on different OS versions from Android 4.1.2 to 4.4.2.

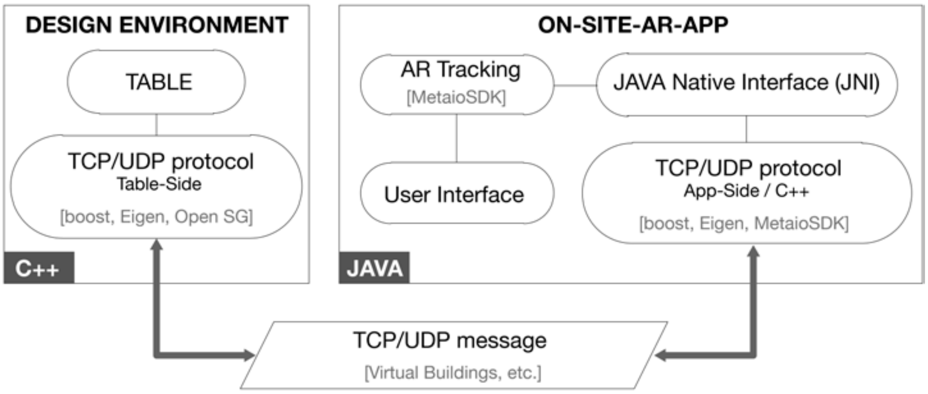

Fig. 13. Software architecture

5.6 Evaluation

For the real-time experience of an AR application it is important that all virtual objects and actions – undertaken by the design-platform-user – are available in the virtual scene in real time. To ascertain how fast the connection between both peers is established and how fast data messages are transmitted to the AR client, we measured the time taken between starting the protocol in the mobile application and the arrival of the first virtual object sent by the table (see Fig 13). The peer connection is always established via a virtual private network (VPN). The time taken, based on an average of 20 measurements, was 122 ms using a Wireless LAN connection and 1807 ms using a mobile network connection (see Fig 12). To measure how long it takes for a single message to be sent from one peer to another, it would be necessary to synchronize times between the multi-touch-framework and the mobile device. Nevertheless, the measurements show that a real-time AR experience is possible using network managed virtual buildings.

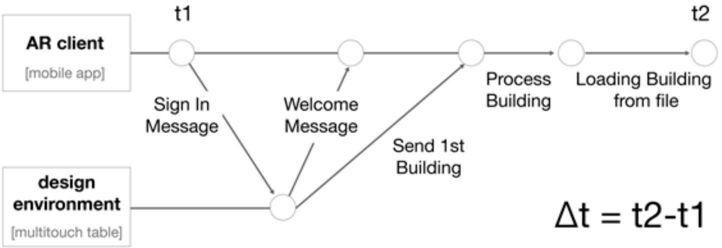

Fig. 14. Protocol time from connection establishment to first received object

Test conducted with different numbers and sizes of virtual buildings showed that a single model of about 200.000 triangles can be displayed at a frame rate of 25 frames per second (FPS). The more buildings that are loaded into the virtual scene, the less detail they should exhibit. Even with 50 buildings displayed at once, the system can still render 1000 triangles per building model at a frame rate of about 25 FPS.

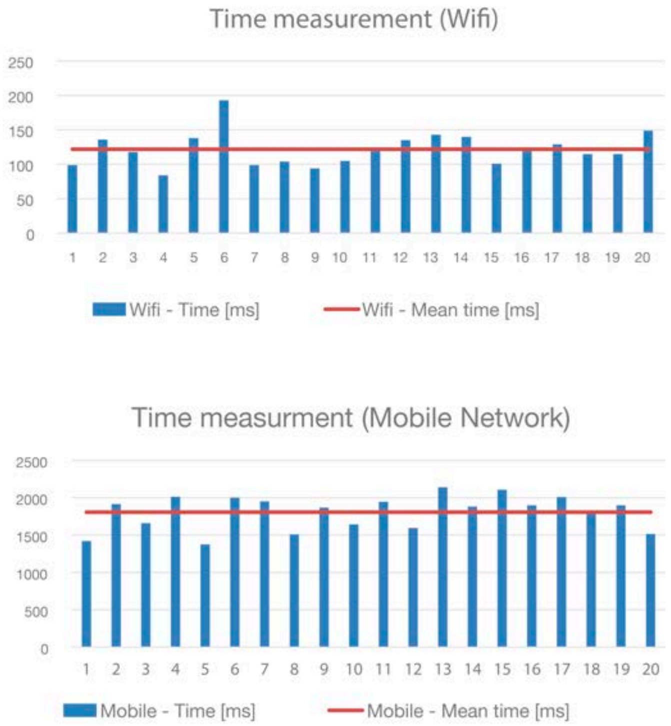

Fig. 15. Time Δt from protocol connection establishment (t1) to displaying the first virtual building (t2)

6 Summary and outlook

The concept outlined in this paper, as well as its prototypical implementation, clearly demonstrate the possibilities of using digital presentation and design exploration tools in a creative context. While augmented techniques are already being used in many areas of digital life, here it is the real-time coupling of established working methods, such as working models and hand-drawn sketches, with digital presentation tools that really opens up new ways for people to discuss and evaluate architectural designs. The seamless connection of both worlds – the physical and the digital – makes it possible to directly come up with and then immersively evaluate architectural ideas. Clients as well as end users can be involved directly in the early design phases of an architectural project where input is most fundamental and least costly for the designer to take account of. It offers an entirely new way of presentation and interaction. The design consisting of a physical working model and hand-drawn sketches is presented directly on site. The incorporation of interactive analyses and simulations likewise makes it possible to assess the impact of a design on the environment more objectively. They enhance the personal subjective impression with additional digital levels of perception such as shading analyses.

The current implementation of the project realises the key components of the project concept. The focus of future work will include the implementation and incorporation of further analysis and simulation tools, as well as the extension of the network protocol to include further functions such as ways of communicating between the participants (e.g. video-calls and the like).

Another possible avenue of exploration is the addition of an annotation and sketching tool to the AR application in which the user can interact directly with the mixed-reality application, the intention being to provide a way for the viewer to give feedback and make suggestions for the discussion process. A key aspect of this will be the bringing together of the different sketches and feedback input into the same virtual model. An aim of future projects is also to better incorporate the real existing buildings in the AR view, specifically aspects such as the projection of simulation results onto them, such as overshadowing or visibility analyses.

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