Supporting Shared Architectural Understanding
Spatial knowledge transfer within Virtual Environments

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Abstract

This article describes how architects can use the strengths of an immersive or semi-immersive virtual environment to create a shared understanding about a design problem. Virtual environments can allow the strong shared understanding under particular circumstances within a collaborative design set-up. The authors will describe which particular factors of shared understanding could be supported within a virtual environment, and which kind of requirements this poses on the virtual environment itself, and the technology which generates the environment. Specifically focused is at how one can create a common understanding of the spatial construction and meaning of a preliminary design idea. Therefore, a major focus is at the transfer of spatial knowledge about architectural space.

Introduction

Virtual Environments have long been seen as the magical medium which should allow a seamless fusion between design and review during the architectural design process. Reality shows, that the largest part of in-use virtual environment applications do not come further as extended walkthrough applications, which allow a limited amount of editing of (often predefined) objects within virtual space. With respect to more advanced modelling functionality, most applications are still desktop based. Though mostly sold as “virtual reality” applications, these desktop applications do not apply the broad range of possibilities and limitations enabled by so called immersive Virtual Environments (VEs), computer generated environments which allow the user to get the illusion of exchanging the real world with a virtual world. This feeling, often referred to as “presence” (feeling of being there) is strongly related to immersion, but involves a large body of factors which will not be handled in this article.

We will primarily deal with the usage of VEs in collaborative design sessions. We focus specifically at how multiple participants in a design process can create a shared understanding of a, in our case, preliminary design. During previous and current experiments at our university with conceptual design tools (Regenbrecht, Donath 1997) in single-use and cooperative design situations, tendencies toward the increased usability of VEs for sharing architectural preliminary design ideas can be observed. These tendencies are supported by other research efforts too, and form an important basis for taking a closer look at the topic.
This article has been written from a bottom-up perspective. We will describe the basics underneath shared architectural understanding and work our way up toward a more functional level. These basics seem to largely lack in most research efforts at the moment and are therefore much more important than starting at top level to observe shared architectural understanding from a functional point of view. During several Virtual Design Studio (VDS) experiments, we observed severe problems with the understanding of exchanged preliminary design ideas between participants (Donath et al, 1999). The ambiguous designs were often only partly understood. The question we want to ask here is the following: how can we create a shared understanding about the spatial characteristics of architectural space between participants about a preliminary idea in a cooperative design process, by exploiting both the possibilities of the content-generator (the computer equipment) and the content itself. Both content and content-generator need to match the requirements coming from the cooperative design process.
Subsequently, we will describe what shared understanding is, and what role our focus, shared spatial knowledge of architectural space, has within this concept. Spatial knowledge and knowledge transfer between participants will be described in detail, after which its effects on the content-generator (the technology) and the content itself will be analysed. Finalised will be how both sides form the basic requirements for VE application development.

Shared understanding

Within a collaborative design process, different participants have to deal with a so called base model, the complete object data set which can potentially be accessed by all participants. Abstractions of this base model can be shared between participants. Shared documents can have a shared underlying representation describing behaviour, function and purpose of the design. The combination of the shared visual and underlying representations forms what is called shared understanding. Shared understanding is of major importance when collaborating in a design process. Different people have different conceptual models (abstractions or interpretations) of the base model, which need to be connected in a coherent way to allow useful communication streams between the participants in the design process.

The Problem

The problem this paper focuses at, is the efficiency of knowledge transfer between different participants in a collaborative design process on preliminary designs.
During previously held Virtual Design Studio (VDS) experiments, we identified that people have problems with interpreting preliminary design ideas. Via the VDS website (space.arch.ethz.ch), participants were able to obtain both textual and visual material on preliminary designs of multiple participants. Unfortunately, participants could often not easily combine the multiple information sources and were regularly confused by the spatial qualities of the designs. Even though models could be dynamically viewed via a VRML-player, models were often hard to interpret. Within the Virtual Design Studio 98 experiment we experimented with the usage of a VE system to review several key designs in the design process. These immersive walkthrough and editing sessions provided us with several tendencies towards the quality of the system to better understand the spatial qualities and there out forthcoming spatial constructions of the designs.
If we combine this observation with the previously stated definitions of shared understanding, an obvious deficiency between the visual information provided via the 3D models and the textual and 2D visual information existed. The ambiguity, or abstractness of the provided visual 3D information (and certain rendered viewpoints) certainly does not aid in the shared understanding. The problem might be sought into the fact, that the conceptual model of the designer is hard to integrate into either the visual representation itself, or the underlying information layer. This de-coupling of information can significantly restrain the possibilities of knowledge transfer. In case of preliminary designs, the exchange of knowledge basically consist of spatial structures which in some form match the requirements of the design task. The information is very approximate, and functional labelling is only partly attached to the visual data. Basically, participants deal with the exchange of abstract spatial knowledge. The question is, how the spatial knowledge integrated in the design and the information which in form is attached to the designer's conceptual model can be structured into the visual and underlying presentations, and how the observation of this data may be influenced by means of a technical medium.

Multidisciplinary and synchronous aspects

Although in this article we only deal with the exchange of information on preliminary designs between architects in an asynchronous way, the counterparts of collaborative design process also have to deal with the same problems. Within a multidisciplinary design process, different views on the base model are even more extreme than during preliminary design. Principally, every participant in a multidisciplinary design process has a largely differing view on the base model, which somehow need to be integrated or matched when communicated about. Such combinations of information have been largely unexplored within the field of immersive VEs, with the exception of the body of work done at overlapping place-specific information on top of a real building, via so called augmented reality techniques.

Within synchronous collaboration, shared understanding can be ported to another level. In our case, we are only dealing with purely visual information (text and images) which a user needs to combine in order to understand and react. Within synchronous collaboration, we often gain extra communication channels of supplying information, namely that of spoken text and direct interaction (for example by using "pointing techniques" to focus on a specific part in a design). These communication channels allow a much richer kind of communication, but, on the other hand, can still hinder the understanding, for example when bandwidth problems of networks cause communication problems.

The Additional Problem

Additional to the problems with conceptual designs, the effects of so called virtual architecture need to be taken into account. At least in the latest virtual design studio experiments, the role of virtual architecture (as being purely digital, mostly non-build-able architecture) needs to be taken under consideration. Virtual architecture often "plays" with normal architectural or physical rules like scale, gravity, form and material. This way, it makes it much harder for an observant to combine virtual architecture with real-world references. Therefor, dimensions and specific characteristics of virtual architecture need to be communicated in some form to the user. How this should be done, is highly speculative and certainly requires further research.

Knowledge of architectural space

Before we can focus at the structuring of knowledge of architectural space (from now on referred to as spatial knowledge), we first need to create a basic understanding of what spatial knowledge is. The model we present is an extension of the model we made earlier in (Donath, Kruijff 1999). Basically, one can observe spatial knowledge as the knowledge which is contained in the user's cognitive map. The cognitive map consists of three strongly interconnected kinds of knowledge (Thorndyke, Hayes-Roth 1982). First of all, landmark knowledge describes the visual characteristics like colour and texture of an environment, and is regularly easy to obtain. Procedural knowledge describes the sequences of actions when we move around an environment. Finally, survey knowledge defines the object locations and inter-object distances in an environment. Within architectural design processes, landmark knowledge is most often communicated via artists impressions, whereas survey knowledge is traditionally communicated via plans. Survey knowledge is perceived as the highest level of spatial knowledge, but is also the hardest to obtain when viewing an environment. The usage and acquisition of spatial knowledge can be observed as a decision making process at two levels: a compute and a search level. The process is a continuous loop of extraction of information from an environment, the combination of this information into a coherent structure, and the usage of this information for future actions or predictions.

This process also plays a distinct role in the preliminary design process, as decision making process to check the requirements of a design with the designers ideas and design outcome. However, this also poses severe problems in the communication of the designs: the abstraction and interpretation of the information in the preliminary design takes place at the designers side – design and cognitive model are closely connected due to the fact that the conceptual design often functions as aid in the idea finding process. This often results in designs which lack certain information, by the simple fact that this information exists in the designers head. During the design itself, and within the steps of refining the conceptual design, the designers should be offered tools which somehow allow the flow of this cognitive information back to the conceptual design, without disturbing the design process.

So, the key factor we are dealing with is the transfer of spatial knowledge. Spatial knowledge transfer has been an issue in research on way finding in VEs over the last decade. Though, this research has primarily focused at how one can transfer spatial knowledge from the VE into the real world, not the transfer of spatial knowledge between multiple participants. Concluding, we need to support two kinds of knowledge transfer:

Transfer of cognitive, spatial information from the designer's cognitive map into the design, Transfer of the out of the previous point forthcoming integrated spatial knowledge between participants.

We will now take a look at how we can support the transfer of this knowledge.

Support of Spatial Knowledge transfer

The support of spatial knowledge transfer within a VE system can be subdivided into two parts, namely that of the content-generator (the technology) and the content itself. The presented methods or factors represent only a part of the complete body of factors, and simply communicate the need for more (formal) evaluation studies to identify more factors.

Content-generator

When we observe a VE system as basically a system consisting of input and output devices, several specific factors can be identified which support the user in the process of obtaining and using spatial knowledge. Some of these factors may seem obvious but are far too often overseen.

- Scaling, stereo and perspective

VEs allow the display of 1:1 scale worlds to the observer. Although correct scaling seems an easy to overcome problem, it often turns out that systems do not render the data into 1:1 scale to the user. The scaling of a virtual world is cumbersome but necessary, and a process in which display size and field of view take an important role. Within most commercial systems, the set-up of output devices is directly connected to the way scenes are rendered, but with custom-made systems, this is often not the case by default. Another factor which plays a crucial role in observing correctly scaled models is the generation of correct stereo images. Interpopulary distance, rendering method and, again, screen size need to be carefully defined. Furthermore, users should take into consideration, that when group sessions are performed within a projection wall system, only *one* person is able to see the correct stereoscopic image, due to the fact that only a very few systems (see Froehlich et al 1995) are able to render stereoscopic images for more than one person. When people are standing close to the person which viewpoint is tracked by a tracking system, this problem is less evident than when the distance between people is larger. So, the "image" often communicated by the media of several people looking at a model in 3D from different perspectives at the same time is incorrect and only describes a completely unworkable situation.

- Stereo versus mono: motion parallax versus stereopsis

In case a slower system is used to render the images in a VR system, one should avoid to offer too many frames per second (fps) in order to render stereoscopic images. Many head-mounted display (HMD) based systems still run in monoscopic to reach a minimum amount of fps (approximately 15). There is a less obvious reason to do this. Although often forgotten, motion parallax (visual motion cues) delivers more information on movement and dimensions than stereoscopic images. Therefore, at least motion parallax needs to be supported, and this is hardly possible within a system which runs far below 10 fps. Stereopsis is a nice add-on to motion parallax, just keep in mind that outside the range of couple of meters, we can not even observe objects in a correct stereoscopic way anymore. Furthermore, in many HMD systems, users surprisingly do not even realise that they are looking at monoscopic images before they are told so.

- Perceptual bias

When we observe an environment in real-life, our observations are always biased, they are never completely correct. Within first-person (egocentric) perspectives, this bias is less than in third-person (exocentric) perspectives, but still considerable (as a rule of thumb, approximately 10%). This perceptual bias also exists within a VE – as a follow-up of the previously stated factors, this bias can be much larger than in the real world. So, when the VE system is not configured correctly, the bias can be much larger than in the real world, resulting in a less usable method of perceiving designs.

- Vestibular information

Although we are already very used at looking at 2D and 3D imaging from a rather static position (ie. on a chair behind a desk), the lack of real-motion cues (vestibular cues) is a factor which needs to be taken in account. As Ruddle (Ruddle et al 1998) found in several experiments, users are better able to judge dimensions when they are able to physically walk around in an environment, instead of passively sitting behind a desktop screen. The is not completely surprising: within real-life we continuously make use of egocentric information (body-centred information), including head and torso displacements, and the movement of our legs (Howard 1991). Therefore, even *fishtank VR systems* (Ware et al 1993) which make use of a desktop screen and a simple tracking system certainly are more valuable for perceptive reasons than a desktop screen only.

- Input devices

Although it may sound strange, the used input devices (and coupled interaction techniques) also have a large impact at the understanding of (complex) visual information. The ease with which we receive rotational and dimensional information influences our perception. This might be best exemplified again by looking at the egocentric reference frame, which we already described in the point about vestibular information. In real life, we often make use of body-centred information sources, like our muscular and joint configuration (proprioceptive information) in order to make spatial predictions, just like with the vestibular cues. Think about how we blindly can bring a mug to our mouth: the proprioceptive information allows us to know exactly how far the mug is from our mouth in order to make predictions for movement. The proprioceptive framework might give us valuable reference measurements (our body) in order to make rotational and dimensional observations, especially if no other reference objects are available. The search for "ideal" input devices is still going on, but for example *props* (embedded real-world objects in a VE) have already proven to give substantial spatial information.

Content

The content support of our VE might be best subdivided into structural organisation and cues. Both irrefutably belong together and strongly influence each other.

- Legibility techniques

Legibility describes how easy we can interpret the spatial organisation of a environment, by recognising specific parts and the interrelationship between those parts in an environment. Legibility techniques already exist since the sixties, when Lynch (Lynch 1960) described the organisation of city structures, which we nowadays are able to find back in almost every American city. The usage of legibility techniques has been a popular method to organise large spatial data structures. A good example form the experiments by Ingram et al (Ingram et al. 1995). Legibility techniques can also be applied to conceptual design in order to understand and communicate the relationships between different parts in the design, even if they are not related to urban structure. For example, think about the allocation of specific functions within a normal building - this functional information can be communicated with the help of legibility techniques.

- Colour coding

A technique which is strongly related to the previously described legibility techniques is the method of colour coding. Colour coding is the method of using different colours and has been widely applied in both computer systems and the real world to communicate the structural organisation and relationships between different parts in an environment (or system). Colour coding can be applied as method afterwards the actual design process, but can also be provided as tool for a designer – sketching with different colour does not necessarily the creative flow into a conceptual design session and can deliver considerable advantages after the design has been finished. Of course, colour coding only supplies information on separating different parts into a larger data set, not on the actual functional characteristics of those parts. This functional information, which we can easily connect to the previously described underlying representation within the framework of shared understanding, needs to be transmitted in another way.

- Transparent information slices

The usage of plans is a common way within 2D design to connect textual information to a spatial construction within construction technical documentation. The creation of abstracted views on a three dimensional source of information is very common within the application of VEs. Think for example about the usage of different slices of information in medical applications coming from medical scans (like MRI) or the usage of clipping planes in a car crash simulation. However, surprisingly enough, textual information has never (to our knowledge) been combined to such slices of information. The overlaying of textual, functional information is certainly possible within higher resolution VE systems. Within lower resolution VE systems, like HMD based systems, this is more problematic due to readability of text, but with the upcoming rise of high resolution projection based systems, this is not a problem. The textual information can either be directly integrated into the slides of information (in case the data set really consists of slides of information) or as transparent overlay over the normal data set. In this case, two data sets are combined, namely the normal data set which is viewed with clipping planes, and the additional information slices which are taken from a separate data set. Of course, this principle will only work if clipping planes can only be moved over the principle axes of a coordinate system, not when the clipping planes are freely place-able. The usage of transparent information slices allows the seamless integration of two and three dimensional sources of information.

- Real-world cues

The application of real-world cues to support way finding within a VE has been subject to plenty of interest. Traditional methods like applying a map or compass, or architectural (like texture, form and light moderations) and natural cues (like atmospheric perspectives or a horizon) can significantly enhance the process of identifying directions and depth within a VE. The true effect, though, on environments which have no real-world content, or which are highly abstracted need to be further examined.

Conclusion

The presented framework of shared understanding support within VEs only forms a first step at the complete body of influencing factors. Although through the last two decades much research has been spent on visualisation techniques, and on spatial knowledge effects of VEs, we are still far from the end – the final frontier of understanding the whole process of designing and communicating conceptual ideas is still far from reached. Formal evaluation of the previously described factors and methods need to be performed in order to validate their importance and, even more important, to identify the full broadness of influencing factors. We may conclude that an thoughtfully designed VE application can certainly offer much potential for designing and communicating conceptual design ideas, but, we are still not at within reach of the ideal application.

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