Collaborative Interaction Concepts for City Planning Tasks in Projection-Based Virtual Reality Systems

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Abstract

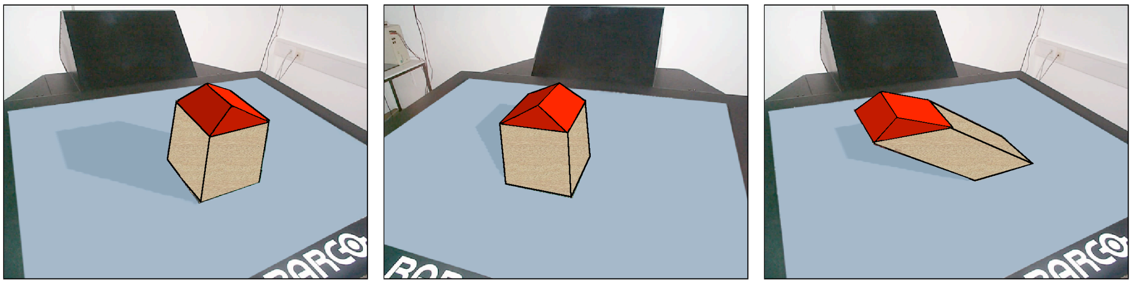
In this paper we propose solutions that allow several co-located city planners to perform domain-specific interaction tasks together in one semi-immersive projection-based VR system. After a registration process, e.g., by posing gestures or by using speech commands, this group activity can be performed either in a *cooperative mode*, i.e., tasks are accomplished consecutively, or in a *collaborative interaction mode*, i.e., users collaborate simultaneously. Both modes as well as multimodal concepts for the registration process are discussed and evaluated. Further VR-based interaction strategies for the city planning domain are presented, which are adapted to the demands of city planners working together in a shared virtual environment.

1 Introduction

Civil works affect both the environment and the inhabitants of a city, since the cityscape as well as the quality of life of the residents is influenced by the composition of buildings, road networks, planting, and green spaces. To facilitate a visual impression of how a proposed building development would integrate into the environment, city planners design development proposals based on *cadastral data*. Cadastral data is available for every town in Germany and contains, for instance, building footprints, the number of floors, parcel boundaries etc. During the planning process there are two main tasks to be accomplished by city planners: (1) defining entities, for example, buildings and recreation areas etc., and (2) integrating these entities into the development plan. The resulting *design plan* illustrates, how the residential area will look like. Often several city planners with different backgrounds, i.e., expertise and knowledge, are involved in such a process. After city planners have agreed to a particular development proposal, two different procedures are commonly used. One approach is to deliver the design plan to an architectural office to generate static visualizations of digital virtual 3D models according to the design plan. Another common procedure is to build physical block models usually made of wood, plastic or paper. In such a shared setup city planners use these approximated 3D models of real buildings to accomplish planning tasks. Thus, city planners can share their knowledge and communicate, e.g., about how to modify the positions of bricks representing buildings. However, changing the appearance or geometry of most objects in such physical models is often awkward since most elements are not modifiable.

Thus, there is a high demand for techniques to improve efficiency of such group activities in the city planning domain. Since the bundling of expert's knowledge has the potential to increase productivity, it is desirable to develop VR-based planning systems simulating such shared space in which teamwork can be performed in virtual environments (VEs) as easily and naturally as in the real world. Hence, the objective for developing such *collaborative VEs (CVE)*, sometimes referred to as *cooperative VEs*, is to provide distributed or locally working teams with a virtual space, where they can coexist, communicate and collaborate while sharing and manipulating virtual data in real-time.

Nowadays implementations of co-located CVEs are based mostly on individual display systems, as see-through or fully immersive *head mounted displays (HMDs)* ([6, 21]). However, to visualize geoscientific data and to support shared exploration of this data, semi-immersive projection-based VR systems are beneficial, since they provide enough space to enable several planners to interact with each other. Within these systems the teamwork process in such CVEs often is constrained since usually only one user is head-tracked and thus perceives a fully perspective-correct stereoscopic image. Though non-head-tracked users are able to observe a stereoscopic image by sharing the head-



(a) left view (b) right view (c) left view with parallax

Figure 1: Parallax problem resulting from different view positions.

tracked user's view frustum, a comfortable interaction and exploration of the virtual scene is not possible. This is due to the fact that the non-head-tracked users' viewpoints differ from the viewpoint of the head-tracked user, which results in unexpected image motions and introduces *parallax*, i.e., a mismatch between the real and the VE perceived by the non-head-tracked viewers ([22]).

Figure 1 illustrates the parallax problem. A virtual building model is displayed on a *responsive workbench (RWB)* ([14]). Figure 1 (a) shows the building rendered from the viewpoint of a user standing on the left side of the workbench; Figure 1 (b) shows the same building as seen by a user standing on the right side. Figure 1 (c) illustrates the building model as seen by a user standing on the left side of the workbench rendered with the view frustum of the user on the right side, resulting in a perspective distorted image. Shearing of the building, which constricts an intuitive exploration, is clearly visible.

This issue complicates the usage of direct interaction techniques for any other than the head-tracked city planner. To involve another planner into the planning process, exchange of the tracked stereo glasses and input devices is required. This can be done either by handing over the devices or by modifying the settings of the tracking system. Moreover, direct interaction techniques need to be improved with respect to the demands of city planners, which are usually not familiar with VR technology. Basic interaction tasks are definitely more difficult to perform in VR than in desktop-based environments.

In cooperation with the city development, city planning and transport planning office as well as the land surveying and land registry office of the city of Münster in Germany, we have developed solutions to support the generation of design plans in CVEs. In this paper we propose a VR-based system for city planning that provides perspective-correct stereoscopic images to all participating head-tracked city planners and which allows comfortable VR-based interaction concepts to generate 3D design plans. Furthermore, no construction of expensive multi-user hardware stereo systems is required. After a registration process, e.g., indicated by gestures, VR-based teamwork can be performed consecutively, or alternatively in parts of one shared projection screen simultaneously.

Related work concerning about CVEs for co-located interaction strategies is described in Section 2. In Section 3 we present the software framework, which enables city planners to develop design plans for residential areas. Our approaches for co-located exploration and direct interaction concepts for the city planning domain are explained in detail in Section 4. Section 5 points out the usability of these approaches in a preliminary study. The paper concludes and gives an overview about future work in Section 6.

2 Related Work

City planning benefits from VR systems, since VR technology provides a better insight into complex spatial data, planners have to deal with. Researchers have proven the potential especially of co-located VR setups supporting teamwork processes for several planning tasks ([8]).

In [6] Boll distinguishes between *cooperation* and *collaboration*. Collaboration denotes the work performed by two or more users in parallel at the same time, while cooperation describes the work performed by more than one user consecutively, but not in parallel. Since cooperation respectively collaboration in VR is a challenging task many approaches have been proposed, which try to extend existing VR systems to CVEs in both local ([6, 10, 12]) as well as distributed VR system environments ([11, 18]). In local CVEs usually HMDs are used and thus collaboration is performed in *augmented reality (AR)* ([21]), such that collaborators can see and communicate with each other. In distributed CVE communication and data exchange is ensured via network transfer. Avatars as representatives of remote collaborators ensure *tele-immersion* by a quasi face-to-face interaction between the participants ([15, 18]). Since in distributed projection-based VR systems every collaborator requires an own display system no distorted stereoscopic images occur. However, when additional users want to participate in a collaboration process either new distributed VR systems have to be set up, or distorted stereoscopic images emerge when users share projection screens with other collaborators.

As described above projection-based display systems provide sufficient projection space to enable CVEs, but usually these systems are capable to project a perspective-correct stereoscopic image to only one user; this issue rather confines projection-based environments to single-user systems with respect to the interaction ([22, 2]). Most solutions to this problem are hardware-based and require additional hardware, e.g., projectors or additional display systems. For example, in [1] a hardware setup for two-user collaboration in a RWB environment with active stereo is introduced. Using this setup a projector displays one image for each eye of both users. The images are rendered either in *user-interleaved* mode, i.e., the images for both eyes are rendered sequentially, first for one user then for the other, or in *eye-interleaved* mode, i.e., the images for one eye of both users are rendered sequentially, before the images for the other eye of both users are displayed one after another. However, the main drawback of this approach is that the refresh rate is cut in half for each user compared to the single viewer setup, which may result in noticeable *flicker effects* ([1]). In [9] this idea has been extended to a multi-viewer projection-based display system, which enables a maximum number of four users to see perspective-correct stereoscopic images. These images are displayed by using further projectors for each user. Hence, this system is hard to scale because for every new user at least one additional projector is required. Other tabletop-based approaches are the *Virtual Showcase* ([3]), the *Lumisight table* ([16]) and the *Illusion Hole* ([13]), which enable multiple users to perceive perspective-correct images. When applying these approaches certain areas on a horizontally mounted projection screen can be observed via a mirror-based setup or physical view barriers, which are attached to the projection screen. The drawback of these approaches is that the users' movements are restricted to certain regions defined by the setup, and that scaling to involve more users requires reconfiguration and recalibration of the setup.

Software-based proposals ([19, 22]) provide partly perspective-correct images to the non-head-tracked users by applying approximations. However, perspective distorted scene content still persists. There are many approaches that advance VR-based interaction concepts ([5, 17]), but these concepts are often not adapted to domain specific tasks with respect to the aforementioned problems.

Thus, there is no approach providing several city planners comfortable collaboration strategies in a single projection-based VR system environment.

3 Residential City Planning

The *3D residential city planner* is an ongoing project involving a group of students at our department, the city development, city planning and transport planning office as well as the land surveying and land registry office of the city of Münster. The objective of this software is to provide city planners an intuitive and natural interface to plan and modify residential areas within desktop- and VR-based system environments.

Since professional city planners desire to maintain intuitive comprehension obtained when viewing a physical block model, we have chosen a semi-immersive RWB environment and a passive rear projection system in combination with an optical tracking system to visualize interactive virtual 3D city models. In comparison to physical block models, the usage of such a VR system setup enables an improved interaction with development proposals, because interactive modifications are possible. For instance, the horizontal or tilted workspace of the RWB is a well-known table-top metaphor many professionals are familiar with, whereas a large rear projection system enables the usage of walk metaphors supporting city exploration from the view of a pedestrian.

During the development phase of the application, city planners expressed their desire for flexible approaches for the visualization of generated virtual 3D city models. Although, photorealistic rendering is important, it is not the only requirement; especially non-photorealistic rendering supports to comprehend structures and relations similar to view physical block models. Furthermore, during exploration interactive frame rates are more important than photorealistic appearance. However, realistic visualizations similar to the renderings provided by architectural offices are desired.

Due to these demands, we have chosen *VRS*, the *Virtual Rendering System* ([7]), as core graphics library for building 3D city models. VRS is an object-oriented and scenegraph-based C++ graphics library. It introduces the usage of two different graphs. *Geometry graphs*, which store the geometry and the visual appearance of virtual objects, are combined with *behavior graphs* that represent their behavior in terms of interaction and animation. Different renderings are ensured with this library, since VRS provides wrapping classes to photorealistic renderers, such as POVRay or Radiance, but also real-time renderers as OpenGL are supported. Furthermore, VRS is extensible to a VR software system by using the *Virtual Reality VRS*

(VR^2S) component ([23]), which handles all VR related issues.

The 3D residential city planning application consists of four conceptual components:

1. **Converter tool**: The converter tool parses and converts the cadastral data into the underlying geoobject model, which is used to represent the corresponding geodata.

2. **Geoobject model**: The geoobject model is the collection of geoobjects and their properties. Components of this model are buildings, building and traffic areas, trees etc.

3. **Visualization component**: This component constructs the scenegraph representing the topological structure of the city model. Each scene node in the geometry graph representing a collection of geoobjects is associated with a visual appearance.

4. **Interaction component**: The interaction component manages required interactions with virtual 3D city models. Standard desktop-based interaction can be performed via a graphical user interface (GUI) based on *wxWidgets*. Alternatively, direct interaction concepts such as arrangement of virtual buildings have been implemented.

Since the cadastral data is geo-referenced, virtual 3D city models can be generated automatically. Because there is no overall accepted standard for storing cadastral information, we have developed an interface, which provides the required generality and flexibility to enable import of cadastral data from different sources. For instance, for the city of Münster the cadastral data stores building footprints, parcel boundaries and other information in Gauß-Krüger coordinates, which are converted during the reconstruction process. Based on this information the system generates a geo-referenced virtual 3D city model of the surrounding area, which is superimposed with aerial photographs to provide more realism and higher recognition.

As mentioned above, VRS uses a scenegraph to represent virtual scenes. Since generated virtual 3D city models may consist of over 50,000 complex, textured geoobjects (see Figure 2), it is not recommend to store each of these geoobjects in corresponding scene nodes, because this would inflate memory requirements for storing the scenegraph and decrease performance when evaluating it. Due to the wrapping mechanism of VRS it is possible to store these enormous datasets with renderer specific optimization strategies in order to achieve a realistic appearance while maintaining interactive frame rates. To further increase performance, optional view-dependent level-of-detail algorithms are integrated to enable switching between different levels of realism. Furthermore, it is possible to switch between non-photorealistic and photorealistic rendering.

Figure 2: City of Münster generated with the 3D residential city planner.

Besides the standard menu-based interaction concepts, such as creation, arrangement or deletion of virtual buildings, different navigation and traveling metaphors can be chosen via menu entries for desktop-based as well as VR-based exploration.

In the next section collaborative interaction concepts are described, which have been developed within the 3D residential city planning project.

4 Co-located City Planning

Since the objective of our approach is to exploit already existing VR hardware to provide an environment for VR collaboration, resources have to be shared. Usually, in a projection-based VR system environment there is only one projection screen available for several users. Thus, to fulfill the demands of projection-based CVEs, assignment of projection space to participants has to be organized. Allowing several users to participate in a teamwork process requires that their view positions and directions have to be tracked. Furthermore, these users should have appropriate tracked input devices for the interaction concepts proposed in Section 4.2. These are the only requirements that have to be ensured to enable several users to participate. Users who currently participate in the collaboration are called *active users*.

According to [6] we distinguish between two modes: the *cooperation* and the *collaboration mode*. Interactive switching between these two modes is possible at run time. Considering the case that a number of active users already interact in one of the two interaction modes and another user wants to participate, this user has to register. The cooperation and the collaboration mode as well as the registration process are explained in the next subsections.

4.1 Co-located Exploration

4.1.1 Cooperation Mode

In some CVEs it is sufficient to accomplish teamwork in a cooperative mode, e.g., several city planners modify a design plan one after another. When using this cooperation mode only one active planner perceives a perspective-correct image and manipulates the design plan, simultaneous collaborations are not supported. Starting with this single-user mode the active planner can explore and interact with the VE immersively until a new planner volunteers for cooperation. To enable the cooperation in a standard projection-based VR system environment, the tracking system has to be reconfigured or devices have to be exchanged, e.g., the active planner and the new planner have to switch their glasses as well as input devices.

To prevent manual exchange of active planners, we propose the following software-based approach. A new planner, who wants to cooperate, can simply volunteer for the cooperation. This can be done by satisfying predefined conditions, e.g., posing a special gesture. Afterwards, when the registration is confirmed, e.g., the current active planner agrees, the planner will change the status from a passive user who only observes the interaction to the active planner by automatically switching the tracking dominance, which determines the tracking settings that define whose head and input devices are tracked. Using this approach only one planner is active at any time, but the seamless switch-over enables groups of participants to cooperate, because the tracking dominance is changed automatically.

4.1.2 Collaboration Mode

As mentioned in Section 1, there are two main tasks to be accomplished by city planners, which can be performed in parallel by at least two planners, i.e., generating geoobjects and arranging these entities into the development plan. Hence, we propose another approach, which enables several city planners to work together in a collaboration mode.

When using the collaboration mode the full screen is split into appropriate viewports arranged side-by-side, in which each active collaborator perceives a perspective-correct stereoscopic image. When additional city planners are incorporated into the planning process, the current viewports are split in smaller viewports again. In the general case in which n active planners collaborate in front of a projection screen which is w *inch* wide and h *inch* high, to each active planner a vertical area of size w/n *inch* $\times$ h *inch* is assigned. When another planner registers for collaboration the new areas have a size of $w/(n+1)$ *inch* $\times$ h *inch*. In the case of removing an active collaborator the viewport areas are scaled accordingly.

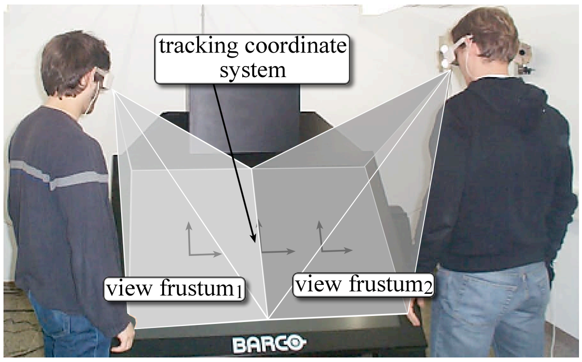


Figure 3: Two users collaborating in front of a RWB.

Since users collaborate in different working areas, and only one tracking system is used to determine the position and orientation of the users' heads and input devices, transformation of the tracking data is required. Figure 3 illustrates this issue. The tracking coordinate system differs from the coordinate system of the individual viewports, and thus the received tracking data has to be transformed from the tracking coordinate system to each active collaborator's viewport coordinate system. In the case of the vertical arrangement of the viewports this transformation for the viewport number i is done by applying a translation vector $t_i^T = (-\frac{w}{2} + (i-1)\frac{w}{n} + \frac{1}{2}\frac{w}{n}, 0, 0)$, where again w is the width of the projection screen and n the number of collaborators.

Although, active collaborators can see the viewports of other active collaborators, a perspective-correct image cannot be observed within these, and thus interactions of each collaborator are constrained to the corresponding individual viewport. However, manipulations of other collaborators can be observed comfortably in the individual viewport while communication as well as face-to-face collaboration is ensured.

This concept is also illustrated in Figure 3, which shows two active collaborators interacting in front of a shared projection screen in a RWB environment. Each collaborator interacts within an individual viewport. Position and orientation of the heads as well as the input devices are tracked by an optical tracking system. The individual asymmetric view frustum of each collaborator is calculated according to the head position and the corresponding viewport on the projection screen.

As described above the shared projection screen can be tiled vertically into viewports and thus, users can collaborate side-by-side. Alternatively, the screen can be tiled horizontally or in a quadratic manner. The drawback of using non-vertical tiling is that conflicts in front of the projection screen are possible, since users may collide because their working areas overlap. Indeed, using this approach the original size of the screen is downscaled; but since large projection screens provide enough space the collaboration mode enables several planners to collaborate in projection-based VR systems, while each collaborator still has a sufficiently large individual viewport at his disposal. The number of active collaborators in such a setup depends on the size of the projection screen and the flexibility required for each user. With horizontally tiled viewports the maximum number of active collaborates strongly depends on the size of the projection screen and the interactivity required by the application. In front of a RWB projection screen that measures $1.36m \times 1.02m$ system environment, we experience best results with two collaborators working side-by-side (see Figure 3). In addition, combinations of both interaction modes are possible to prevent too small viewports. The collaboration mode allows collaborators to interact simultaneously in an appropriate number of separated viewports each with a certain number of cooperators who perform cooperative interaction in their viewports.

4.1.3 Registration Process

To reduce the cognitive effort of involved planners the number of required gestures is small. A *notify-gesture*, e.g., consisting of a combination of a glove event (pinching thumb and index finger) and a corresponding tracking event (hand is higher than the head), indicates an announcement for a participation in the interaction process. Afterwards current active planners can accept this announcement with the *confirmation-gesture*, e.g., posing a circle by pinching thumb and index. After a successful announcement for the teamwork the actions described in Section 4.1.1 and Section 4.1.2 for exchanging active cooperators or adding respectively removing active collaborators are initiated.

Since in projection-based VR systems there are confined resources, e.g., tracked stereo glasses or viewport space, these resources have to be shared appropriately. As mentioned before, users have to register to participate in the teamwork process. For the registration we have implemented three different strategies, called *announcement*, *invitation* and *time-dependent switch*:

To announce for collaboration city planners can perform predefined actions, e.g., pose a gesture, which indicates that the planner wants to participate. If this planner has appropriate rights or after a privileged user accepts the announcement the teamwork process is initiated as described in Section 4.1.1 and Section 4.1.2. Alternatively, city planners can invite other planners for teamwork. Another strategy enables an automatic switch of the active city planners after a certain time period. This time-dependent exchange of active planners may be useful in presentation scenarios, where the exploration of development proposals by groups of users, e.g., citizens, has to be ensured.

To organize the administration of many participants in a CVE a hierarchical authorization structure similar to the structure used in operating systems may be implemented. The type of access right can be defined by an administrator according to profiles that are associated to the participants. Thus, for instance, higher privileged users can allow or deny cooperations respectively collaborations with lower privileged users. Usually in a projection-based CVE teamwork is performed between a small numbers of users, sharing of the resources can be realized by assigning equal rights to all users. Hence, in our CVE setup the collaboration is done by communication between participants and the described registration processes, indicated by gestures.

4.1.4 Multimodality

Although, city planners can see each other, application of the gesture-based registration processes has shown that planners often do not observe each other when they perform gestures. This is due to the fact that the active planner usually concentrates on the planning process, whereas non-active users stay beside or behind the active one. To support drawing the attention of the active planner to another city planner who wants to participate in the planning process, we have integrated multimodal concepts in the registration process. For example, when a city planner performs an announcement, a spatial sound propagates from the position of this user. The position-dependent sound propagation gives an additional clue about which planner volunteers for interaction.

Our approach enables also further multimodal concepts such as haptic feedback as a hint for a registration, if the planners' input device features corresponding technology.

4.2 Co-located Planning

With the concepts introduced in Section 4.1 we provide city planners with a solution, which allows an easy extension of existing VR hardware setups to CVEs. In the next subsections we present intuitive interaction concepts supporting VR-based co-located development of design plans. As mentioned before, such processes can be typically divided into: (1) generation and (2) integration of virtual geoobjects.

4.2.1 Generation of Virtual Objects

For this purpose the 3D residential city planner incorporates a *virtual building editor*. Within this editor new buildings can be created or existing ones

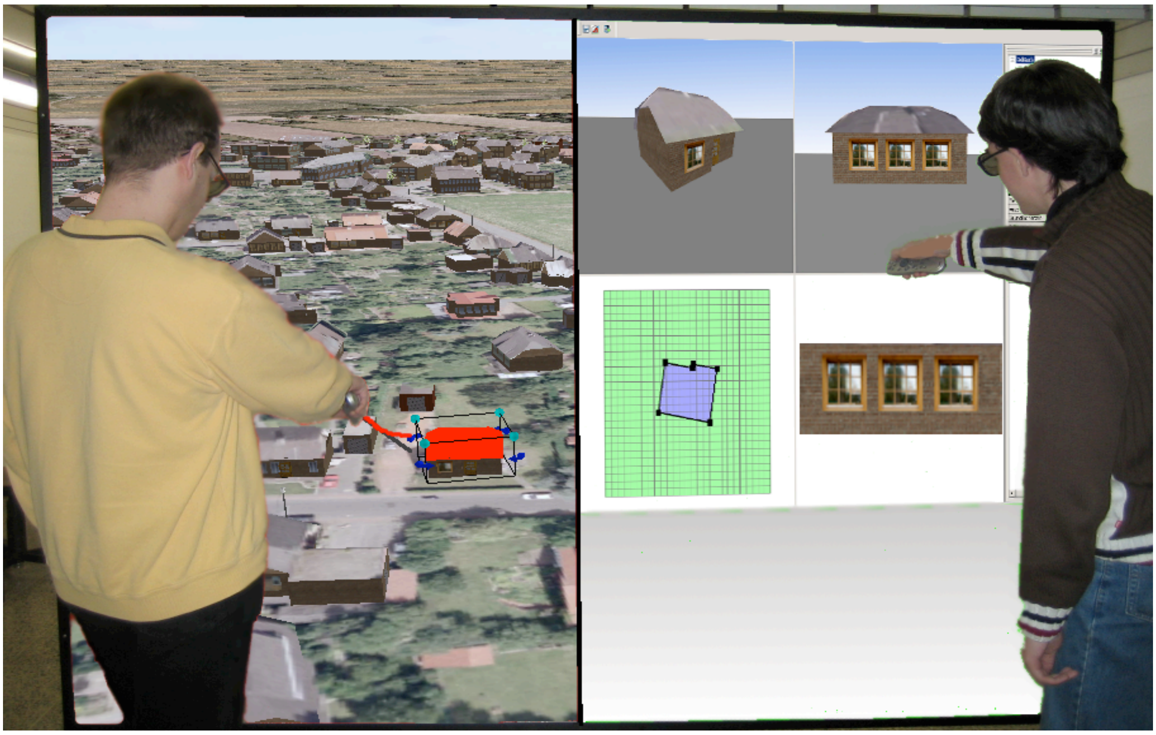


Figure 4: Collaboration mode showing a user generating virtual buildings via the building editor (right viewport) and a user integrating them into the 3D city model (left viewport).

can be modified, whereas all relevant properties of a considered virtual building can be altered.

Figure 4 (right viewport) shows the GUI of the building editor. The editor is a multiple view system composed of four views. In the upper-left view a 3D preview of the virtual building shows its integration into the surrounding. The surrounding can be visualized in a semi-transparent way in order to maintain the focus on the building to be manipulated, but also to allow a preview of the integration. The lower-left view displays two-dimensional buildings footprint, and enables the city planner to modify the ground plan of all floors of the building. Moreover, an arbitrary wall can be selected and thereupon the selected wall will be in the focus of the view in the upper-right of the editor, i.e., the virtual camera is steered to that wall. The lower-right view focuses on the current wall, which has been selected in the bottom-left or upper-right view. Using that view the city planner can add or remove windows or doors and he can assign corresponding textures to them. By overlaying the development plan onto the 3D preview or onto the orthogonal lower-left, the city planner gets information about the constraints that have to be incorporated in the parcel boundary area, e.g., maximum allowed height between floors etc. After finished modeling a virtual building, it can be imported into an arbitrary virtual 3D city. Moreover, a once generated virtual building can be stored in a virtual building library that can be accessed from within each new development plan.

4.2.2 Integration of Virtual Objects

Although, VR environments provide the possibility to manipulate virtual objects in an intuitive manner, e.g., by using *virtual hand* or *virtual pointer metaphors* ([17]), these concepts are often limited, because the cognitive effort for an interaction is definitely higher in VR than the effort for the corresponding interaction in the real world. In addition, it is often difficult to perform precise interactions because of tracking errors and hand tremors. For example, it is hard to select small or distant objects. Thus, generic interaction tasks need to be enhanced.

In order to advance such basic interaction tasks we proposed the *improved virtual pointer* (IVP) metaphor, which avoids most disadvantages of current interaction metaphors ([24]). This approach allows city planners to select a desired geoobject with a virtual pointer without requiring an exact hit. While a straight ray is used to indicate the direction of the virtual pointer, an additionally visualized bendable ray points to the closest selectable geoobject or item (see Figure 4 (left viewport)). After selecting the desired geoobject, manipulations can be performed similar to the manipulations of physical block models. The movements of the virtual input device are transferred by advanced mapping approaches to the selected geoobject, which supports also the manipulation of distant objects outside the immediate reach of the city planner ([24]). Due to this mapping strategy virtual geoobjects can be arranged very comfortably and intuitively.

To reduce the cognitive effort for such 3D interactions, we have integrated *3D widgets* into the manipulation process as illustrated in Figure 4 (left viewport). 3D widgets provide an easy way to manipulate objects with six degrees of freedom (DoF) by constraining the simultaneously manipulated degrees to one. Widgets provide handles for translation, rotation, and scaling of virtual geoobjects. Thus, six DoF manipulation tasks can be decomposed to a sequence of simple two-dimensional interactions.

Furthermore, we support interaction with multimodal feedback. For example, when a selection is possible, e.g., the selection ray hits a virtual building, the users perceive an acoustic feedback and a slight vibration, if the input device of the city planner is equipped appropriately with corresponding vibration units. The intensity of both signals depends on the position of the virtual building with respect to the planner's position, e.g., with increasing distance between city planner and building the vibration signal decreases.

Figure 4 shows two planners in front of a passive rear-projection screen. The right user generates virtual buildings using the described virtual building editor, whereas the left user arranges these buildings in the 3D city model by using the IVP metaphor.

5 Usability Studies

We have evaluated the CVE interaction concepts in two usability studies performed within the context of the 3D residential city planner project. The 25 subjects chosen for the test series were familiar with residential planning environments. Most subjects were geoinformatic students, but also landscape ecologists, computer scientists and mathematicians participated in the usability study.

5.1 Tasks

To evaluate the co-located exploration concepts described in Section 4.1 we have performed a usability study in which we compare the proposed approaches for cooperative and collaborative as well as single-user interaction. Since the results of this study should give a first impression of how far the described concepts are accepted and applicable by VR-experts and -novices, we have requested 10 participants to evaluate the approaches. The participants were VR-novices such as students of computer science, mathematics and geoinformatics as well as research assistants, which are familiar with VR technologies.

We presented the application to a pair or a group of three participants, one of whom wore tracked shutter glasses, whereas the others wore non-tracked stereo glasses. To change the active user, the participants had to switch the glasses. In the second phase, both participants wore tracked glasses, and we tested the cooperation mode with the proposed registration processes, initiated by the described gestures. For each approach, i.e., announcement, invitation and time-dependent switch, we gave a short introduction into the functionality of the techniques. In the last study phase, we used the collaboration mode to find out in how far the visualization on a tiled projection screen affects the subjective perception of the participants. For the evaluation of the usability study, the participants were asked to review the different interaction modes and techniques for the registration process. Most questions were based on a five-point Likert scale (from 1 to 5 associated with corresponding ratings).

For the evaluation of the concepts described in Section 4.2, 15 subjects had to accomplish several selection and positioning tasks, i.e., randomly marked virtual buildings had to be selected and arranged in a development plan by using different interaction metaphors. These metaphors included the IVP metaphor and a simplification, called *sticky-ray metaphor*, the *ray-casting technique*, and the *sticky-finger technique* described in ([24, 4, 20]). We have evaluated the time needed for each subtask and the accuracy achieved with a particular metaphor.

The most significant results are summarized in the next section.

5.2 Result

The manual switching of tracked glasses and input devices takes at least five seconds and as expected participants feel inconvenient about it. They rather prefer to watch a virtual scene without tracked glasses than to switch the glasses again and again. This is also confirmed by the survey, which points out that the perspective distortion as well as the jerky leaps in the visualization occurring when an active user is changed, are considered as minor disturbance (average 2.3 respectively 2.1 where 1 corresponds to non disturbing and 5 corresponds to very disturbing).

As depicted in Figure 5 the review of the quality and size of the visual representation in the two-user split-screen collaboration mode shows that these qualities do not decrease significantly, and distraction by perception of other users' viewports has been evaluated as minor (5 corresponds to sufficient size and quality of projection screen (1), no

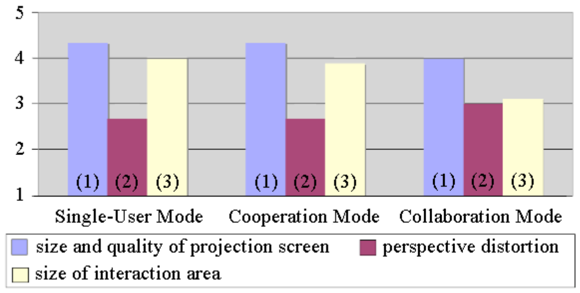


Figure 5: Results of the user survey.

perspective disturbing distortion (2) and sufficient size of interaction area (3), whereas 1 corresponds to insufficient size and quality of projection screen (1), very perspective disturbing distortion (2) and insufficient size of interaction area (3)). The interaction space in front of the RWB has been evaluated as sufficient, but a larger interaction area would be preferable especially in the split-screen collaboration mode and for more than three planners.

The complexity and usability of the proposed gesture-based registration process has been evaluated with 4.8 on average (1 corresponds to very complex and not intuitive, 5 corresponds to not complex and very intuitive), and support by multimodal feedback has been reviewed as very helpful (on average 4.1 where 1 corresponds to not helpful, 5 corresponds to very helpful).

Furthermore, Figure 5 points out that the interaction space in front of the RWB has been evaluated as sufficient (average 4.2 on a five-point Likert scale (3), where 5 corresponds to sufficient size of interaction area, whereas 1 insufficient size of interaction area), but a larger interaction area would be preferable especially in the split-screen collaboration mode.

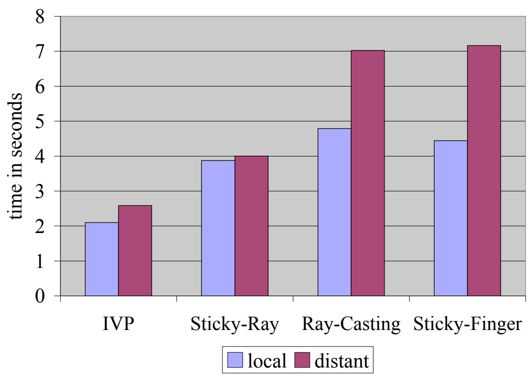


Figure 6: Results of the usability test.

The most significant results of the evaluation of the direct interaction concepts proposed in Section 4.2.2 are illustrated in Figure 6. This chart shows the time needed for a selection when using the different metaphors. The results clearly show that the IVP metaphor improves efficiency and that selections are performed faster for local object selection, i.e., selection in the immediate reach of the user, as well as for selecting distant geoobjects. Also performing the required manipulations was more accurate and precise using the described approach. The participants have evaluated the IVP metaphor as the most intuitive, easy to use and easy to learn metaphor in comparison to the other approaches. Although a significant performance increase could not be observed, the participants felt convenient and confirmed during interaction processes when receiving multimodal feedback.

6 Summary

The concepts proposed in this paper prove the potential of co-located VR-based city planning systems for teamwork planning in semi-immersive VR systems. Upscaling and downscaling at run time for a varying number of collaborators is ensured using the co-located exploration approaches without the need of adding or removing any hardware. In addition the interaction concepts for the planning process presented in this paper prove their advantages.

The usability studies point out the applicability and potential of the described CVEs. Currently, the land surveying and land registry office evaluate a prerelease version and the city development, city planning and transport planning office will test the system in a real planning process soon. When these field studies are finished, modifications of the actual application or integration of further functions will be accomplished.

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