A Multiple View System for Modeling Building Entities

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Abstract

Modeling virtual buildings is an essential task in the city planning domain whereas several aspects have essential influence. Planners have to deal with different types of potentially multiform datasets; moreover they have to consider certain guidelines and constraints that are imposed on the development areas to which buildings are related. The planning process can be divided into different subtasks with varying requirements regarding the interaction techniques that are used for their accomplishment. To incorporate these aspects multiple view systems have proven enormous potential in order to provide efficient user interfaces. In this paper, we present strategies for modeling virtual building entities via a multiple view system as part of a 3D decision support system that enables the intuitive generation and evaluation of building proposals. City planners have been involved in the design process of the system, in particular the multiple view concepts. Therefore each view of the system, which visualizes different aspects concerning the underlying models, meets the demands of city planners. Furthermore, we present both coupled and uncoupled interaction techniques between different views with respect to requirements of the city planning domain.

Keywords— **Geovisualization, city planning, building entities, multiple view systems, coupling techniques**

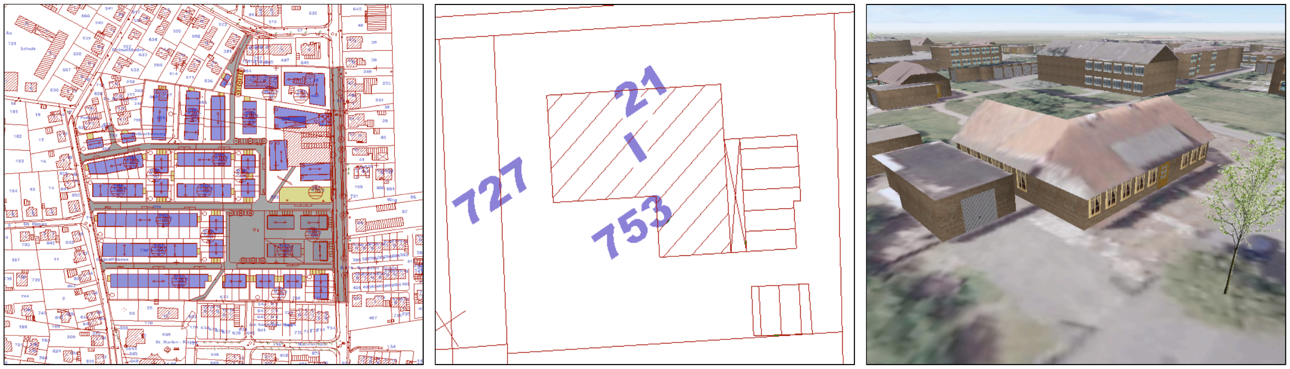
1 Introduction

City planning tasks are of major importance for civil works since both the environment and the inhabitants of a city are affected. The cityscape as well as the quality of life of the residents essentially depend on the appearance of different entities such as road networks, planting, green spaces, and recreation areas, and in particular buildings.

To define such virtual buildings city planners usually use two-dimensional CAD concepts to design the development for a certain area based on existing *cadastral data*, which is available for every town in Germany. Based on this cadastral data city planners define *development plans* as depicted in Figure 1 (a). Development plans incorporate several geospecific entities, e.g., buildings and recreation areas, associated with a set of constraints, which specify what types of geoobjects are allowed and what requirements have to be incorporated. When a development plan is provided city planners can design several geoobjects, in particular building entities, which are associated to certain buildings areas in the plan. When finishing this design process, the resulting *design plan* illustrates, for instance, potential home buyers how the residential area will look like.

As depicted in Figure 1 (a) the data of development or design plans usually contains building footprints, road networks, parcel boundaries and other information in a vector-based format. A virtual building defined in this format is stored by means of the building footprint, number of floors and floor's height, roof type and further information given by numerical or textual hints. Figure 1 (b) shows the cadastral information for an example building of the development plan illustrated in Figure 1 (a). The outlines define the building footprint. The hatching enclosed by the outlines determines the type of roof. In this case a diagonal hatching denotes a gabled roof, whereas, for instance, vertical straight lines specify a flat roof. Numerical values in the outline encode further information, e.g., roman numbers represent the number of stories, and textual information encodes the address. Figure 1 (c) illustrates the corresponding 3D virtual buildings automatically generated from this two-dimensional vector data.

One drawback when using such 2D CAD concepts is that they do not allow a realistic 3D preview of the building regarding facades, roof types, and its integration into surrounding properties. To facilitate a realistic impression of how a building would visually integrate into the environment and to enable communication regarding development proposals, two approaches are commonly used. One approach is to deliver the development plan to an architectural office. On the basis of this plan architects generate virtual 3D models and return exemplary three-dimensional visualizations of these planned areas to city planners. This procedure has the following two major shortcomings. First, the returned visualizations are static insofar as city planners cannot explore the 3D models interactively. Second, city planners cannot perform modifi-



(a) Development data (b) Cadastral data (c) 3D virtual building

Figure 1: Example section of a city development plan embedded into cadastral information (a) and an enlarged view of the cadastral data showing a virtual building (c) and its 3D representation (c).

cations to the 3D models, which, for instance, have been proposed after reviewing the 3D visualization. Instead, the architectural office has to be asked again to incorporate these modifications into the 3D model. During a planning task, this usually takes several iterations resulting in inefficiency as well as unnecessary expense. The second common alternative to get a realistic impression of a virtual building is to build a physical block model usually made of wood, plastic or paper. After a physical block model has been finished, performing modifications is often awkward, since most elements are inflexible and fixated to the model, so that they have to be removed and replaced by new elements. For these reasons, simpler solutions to visualize planned development areas are desired.

In cooperation with the urban 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 a 3D decision support system to solve these problems ([16]). This so-called *3D residential city planner* enables city planners to generate and evaluate design plans by means of creating and manipulating geoobjects, in particular virtual buildings, and integrating them into building areas.

We have chosen *VRS*, the *Virtual Rendering System* [6], as core graphics library for the 3D residential city planner. VRS is an object-oriented and scenegraph based C++ graphics library. It introduces the usage of two different graphs. *Geometry graphs*, which store the visual appearance of virtual objects collected in scene nodes, are combined with *behavior graphs* to 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, e.g., OpenGL, are supported.

The 3D residential city planner consists of four conceptual components: The **converter tool** parses and converts the cadastral data into a scenegraph structure, which is used to represent the corresponding geodata. The **geoobject model** is the collection of geoobjects and their properties. This model is generated during the parser process of the converter tool. Components of this model are buildings, building and traffic areas, trees etc. The **visualization 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, e.g., by assigning colors or textures. The **interaction component** manages required interactions with virtual 3D city models. A graphical user interface (GUI) based on *wxWidgets* allows to access certain interactions.

When using the 3D residential city planner, at first the cadastral data and the development plan are converted into a three-dimensional representation as illustrated in Figure 1 (c). 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. 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. To generate a design plan based on this 3D model, city planners can create or import several geoobject entities such as roads, plant and in particular building entities.

Generating or manipulating virtual buildings that shall be integrated into a design plan is a complex task consisting of several subtasks. These subtasks make various demands on the interaction, since the dimensions and types of the underlying model vary, and restrictions associated with certain development plans are different for each building area. When developing a virtual city model, several sources with different dimensionality have to be combined. For example, vector-based cadastral data and development plans as well as raster-based aerial photographs and textures are two-dimensional, whereas the buildings height and roof geometry describe three-dimensional structures. Hence, it is beneficial to use different interaction techniques to accomplish the tasks to be performed. For example, manipulations of building footprints are most intuitive to perform by changing the vertices in two dimensions via drag and drop or by specifying numerical values. In contrast, roof types or integration of virtual buildings into surroundings can be evaluated best in three dimensions. Furthermore, there are certain restrictions regarding the allowed operations, e.g., in certain building areas usually only certain roof types are allowed, or distances between buildings as well as buildings and streets have to be fulfilled. In addition, to allow a better comprehension when viewing a virtual building different levels of abstraction are required, e.g., city planners desire both photorealistic as well as non-photorealistic, e.g., block model, visualization for virtual buildings ([3, 7]).

All these different issues and requirements have to be considered, when providing an intuitive user interface to support the efficient generation of virtual buildings. However, to prevent a contextual switch when city planners perform building planning tasks incorporating multiform datasets, different aspects can be combined in *multiple view systems* ([11, 14, 13]). According to North and Shneiderman ([11]), multiple view systems are interactive systems, which use two or more distinct views to support the exploration and investigation of conceptual entities. This can be achieved by presenting different aspects of the same information in different views in order to support users to better understand structures and configurations ([1]). Such multiple view system are commonly used, and their application has emerged as a valuable strategy for many domains, for example, medical visualization, information visualization, architectural design, 3D modeling, or web browsing ([13]). For instance, medical visualization applications usually exploit three views providing axial, coronal, sagittal slices of an object to be analyzed ([12]). Empirical studies of such multiple view systems have pointed out significant advancement in user performance in a variety of these situations.

As mentioned above the concept of multiple view system is widely used in several application domains. For the geovisualization domain, in particular city planning, there are some approaches providing multiple views according to the aforementioned different dimensions of the datasets ([5, 4]). However, in these systems only a subset of the required information is presented, e.g., the surrounding of the building as well as the underlying restrictions of the development plan are ignored. Thus, when using these systems the constraints that affect the design process have to be considered by the city planners using different strategies. Therefore, city planners have to use another application, which shows a digital version of the development plan, or a printed version has to be exploited. However, it would be desirable to combine these aspects in a computer aided design process. To the authors knowledge none of the currently available multiple view systems for city planning, in particular modeling of virtual buildings, incorporates the addressed multiform requirements.

In this paper, we present a multiple view system for designing virtual buildings that meets the demands of city planners. Furthermore, it is shown that multiple view systems provide enormous potential for the domain of city planning if appropriate interaction concepts are supported, e.g., both a tight coupling between the views as well as autonomous interaction should be possible. The paper is structured as follows. Section 2 discusses the demands of the city planners with respect to the building modeling process. Section 3 introduces the building editor and describes the coupling of multiple views and how interaction is performed. Section 4 shows the result of a preliminary usability study in which a planning process based on the proposed multiple view system is compared with a planning process based on the ordinary 2D single view procedure. Section 5 concludes the paper and gives an overview about future work.

2 Requirements of City Planners

Since multiple view systems provide the potential for efficient user interfaces, their application in 3D residential city planning systems to support the intuitive design of virtual buildings is desired. However, as described in [2], it is a challenging task to chose an appropriate number and kind of views in order to provide intuitive and comprehensible interfaces and not to overstrain the user. Since the urban development, city planning and transport planning office as well as the land surveying and land registry office of the city of Münster in Germany were involved closely into the development process of the 3D residential city planner, in particular the *multiple view building editor*, it has been ensured that all developed concepts are relevant with respect to the demands of the city planners.

During the design process of the multiple view building editor the city planners have been involved during the important phases. At first, in cooperation with the city planners we decided to apply multiple views for the computer aided planning of virtual buildings. Following, in a selection phase a set of coordinated views to be used were identified, and we determined how information has to be segmented to the used views. In the following presentation phase, we specified how the views should be presented. Due to the fact that many different arrangements on the screen are possible as well as different visualizations inside each view, we designed proposals of possible visualizations and arrangements. The city planners tested and evaluated these proposals and gave us feedback and hints we integrated to obtain an improved version. This procedure took several iterations. In the interaction phase we had to determine, which interactions among the different views are possible with respect to the demands of city planners.

The way in which multiple view systems visualize certain aspects of datasets depends on the intention of the view and the characteristics of the data. Multiple realizations can be formed from the application of different visualization algorithms, by changing the mapping algorithm on the data or by using the same visual form, but rendered from different positions and orientations ([15]). These aspects and factors have essential influence on the choice of views, choice of data to displayed in each view, choice of interactivity provided for each view and its level of coupling between the views.

In the following subsections these demands on the design of the building editor, which affected the described phases, are pointed out.

2.1 Miscellaneous Views

As mentioned in the introduction, one major drawback of the usage of two-dimensional CAD systems is, that usually only one preview of a building, e.g., orthogonal view onto the building footprints, is supported. City planners exploit **photorealistic 3D previews** provided by architectural offices, but also schematic representations given by building block models, to obtain a comprehensible impression of how potential buildings would look like and how they visually integrate into the surrounding. Although these representations provide city planners with valuable information about the appearance of certain buildings, the obvious drawback results from the fact that city planners perceive these impressions not during the actual design process. Hence, city planners desire to have more sophisticated control about the 3D previews of building entities in order to provide them with additional information and advanced comprehension especially during the design process. Thus, **interactive exploration** supported by intuitive navigation concepts, which allow to view a building entity from different perspectives, is a major demand. However, the demand for previews is not restricted to photorealistic visualization of virtual buildings, city planners also desire different levels of abstraction, i.e., realistic representations but also schematic illustrations provided by **non-photorealistic renderings (NPR)**. Such **conceptual views** enable them to evaluate the modifications applied to a particular building in an abstract way. To assess modifications in the context of the surrounding of such buildings, i.e., building areas, other buildings, streets etc., city planners desire also **contextual previews** that provide them with an overview about the building's surrounding.

2.2 Modification of Properties

City planners usually use two-dimensional CAD systems in order to change the features of virtual buildings with respect to their **main properties**, i.e., building footprints and building's height, in particular the number of stories and the height of each story as well as the jamb wall. When using 2D CAD systems, they define building footprints in 2D and add textual flags indicating further information such as building's height, roof type etc. They desire to be able to specify these and further properties in an intuitive way. Furthermore, city planners request to be able to generate arbitrary complex buildings, for example, with overlapping footprint edges, extra stories built on top of already existing building structures etc. Furthermore, city planners desire flexible **roof types** for a building. Several generic roof types need to be supported, e.g., flat roofs, gabled roof, hipped roof etc.

Although change of **visual appearance** in terms of facades or roof covering etc. is usually not performed by city planners, they desire to be able to texture facades by applying brick, wood, plaster or photographic textures; moreover, positions and sizes of doors and windows should be modifiable in order to enable a more realistic impression.

2.3 Handling of Multiple Data Models

City planning deals with multiple data models from different sources that contribute to the generation of virtual city models. As mentioned before, for example, cadastral data and development plans are given in a vector-based format, whereas aerial photographs and textures, e.g., for ground, roofs or facades are given in raster-based formats. Furthermore, the cadastral data contains several layers; building footprints are stored in one layer, whereas streets, or textual information are provided in other layers. In addition, when generating a design plan, city planners have to incorporate the underlying terrain model, which affects the appearance of the cityscape.

There are many properties of a building, which can be defined in **one dimension**, for example, number of stories, a stories height etc. Other features of a building entity such as building footprints are given by **two-dimensional** data, whereas a realistic building preview can be provided best in **three dimensions**. Besides these typical requirements on handling multi-dimensional datasets, city planner desire to be able to evaluate the behavior of shadows cast by buildings over time giving a **forth dimension**. Thus, potential home buyers may estimate the insolation, for example in order to set up solar heating or to plan balcony and garden installations.

2.4 Coupled vs. De-Coupled Interaction

Many of the aforementioned requirements argue for the usage of a multiple view system. Once multiple views have been generated they may be explored and manipulated simultaneously; in this case the views are said to be *coupled*. A *tight coupling*, sometimes referred to as *linking* or *coordination*, of the views is important to enable the synchronization during interaction processes such that users can relate information between the views. Furthermore, elements displayed in several views may be jointly selected in one view, which causes their highlighting in the corresponding views ([8]).

Most of the described demands require a **tight coupling** for the linkage between the different views, for example, all modifications of the geometry influence the visual appearance of the 3D building preview. However, sometimes it is desired to allow an unconstrained coupling in order to provide the user with more autonomy when interacting with a single view of a multiple view system. Some building planning operations can be performed in a **de-coupled** way, i.e., interactions performed in one view need not affect another view. For instance, if an NPR visualization is chosen for the preview, it may be changed for another view also, e.g., a lateral view, but it need not. In general, however, most interactions should be **cross related** to enhance the navigation process when using a multiple view system ([10, 15]). For instance, the selection of a particular wall in order to change the position of windows or doors is more easily performed in a two-dimensional view in comparison to a selection in a lateral view in which the desired wall is occluded, for example, by another wall. This is due to the fact that the virtual building has to be rotated first in order to be able to select the desired wall.

Furthermore, as pointed out by city planners many interaction concepts require different dimensions. For example, modifications of two-dimensional footprints are more easily accomplished in two dimensions, whereas the selection of the floor on which the modifications shall be performed is difficult in 2D, since it would require a mechanism to tab through the stories. Hence, an active story is more easily to specify in a lateral view or 3D preview, and thereupon the footprints are modified in a two-dimensional view.

2.5 Constraint-based Interaction

When developing a virtual building several constraints have to be incorporated, which influence the interaction with geoobjects and restrict their manipulability. These constraints classify into *geometrical*, *topological*, and *structural constraints*. **Geometrical constraints** restrict interaction processes referring to the geometry of building entities, e.g., only floor-wise scaling is supported, whereas a maximum building height has to be observed. **Topological constraints** determine relations between buildings. For instance, a development plan can define a minimal distance between geoobjects, such as distances between buildings or distances between buildings and streets, which have to be maintained. City planners can define **structural constraints** in a development plan, which relate a building entity exactly to one building area. Furthermore, the city planner can define further constraints in terms of the orientation of building entities or approved roof types. Besides such constraints, there are further dependencies, which have to be incorporated. For example, the buildings in a certain area must be uniform in terms of their visual appearance.

Although many constraints are defined in development plans, city planners desire to be able to suspend these constraints. Hence, a mechanism is needed to turn off constraints during interaction. Nevertheless, city planners want to get informed about the constraints and restrictions, which are imposed on certain building areas.

3 Multiple Views for Modeling Buildings

Regarding the requirements discussed in the previous section, we have developed a multiple view building editor system, which provides city planners with several distinguished views supporting appropriate interaction techniques. This section explains this multiple view system in detail; in particular the features of each view as well as the associated interaction techniques are pointed out. Furthermore, the coupled and de-coupled interaction concepts between the different views are discussed.

3.1 View Layout

As illustrated in Figure 2, the proposed multiple view system is composed of six different views. In addition, each window representing a view and its properties is used as a floating window and can be docked to the multiple view system. Hence, the arrangement of the views and

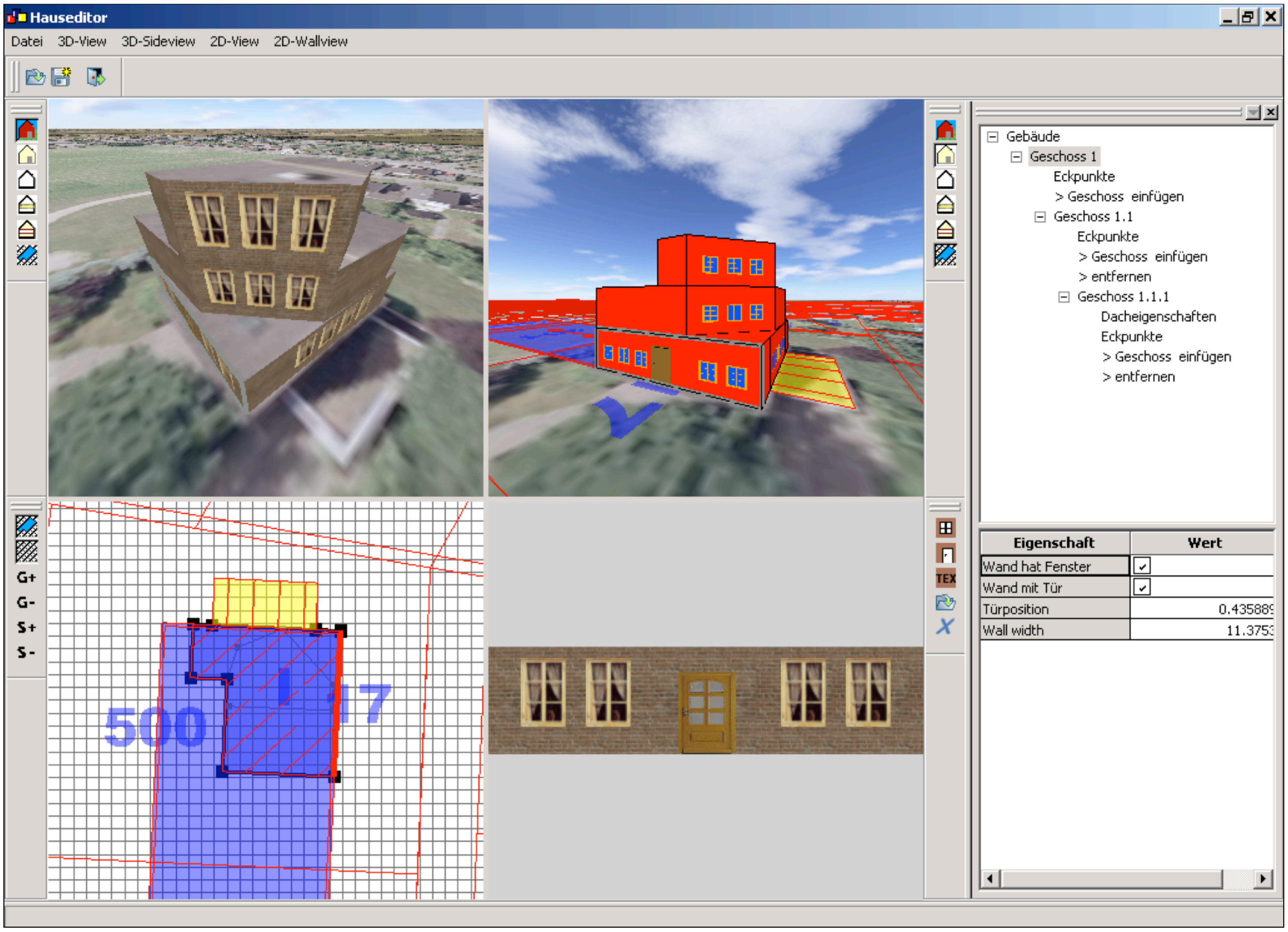


Figure 2: The building editor is composed of six views: contextual 3D preview (upper-left), 2D vector-based topview (lower-left), lateral view (upper-middle), orthogonal wall view (lower-middle), hierarchical structure view (upper-right), and property view (lower-right).

their sizes are variable; thus they can be adapted in a user-definable way.

When using the multiple view building editor either an existing building can be loaded into the editor, or a new building can be created, whereas thereupon the building is in the focus of each view. In the upper-left view, referred to as *contextual 3D preview*, a three-dimensional preview of the virtual building shows its integration into the surrounding. The neighbor buildings can be either displayed in order to allow a preview of the integration or they can be ignored in order to maintain the focus on the building to be manipulated. The *vector-based topview* in the lower-left view shows a two-dimensional presentation of the building footprint, it enables city planners to modify the ground plans of all buildings' floors. Moreover, an arbitrary wall can be selected and thereupon the selected wall will be in the focus of the view in the upper-middle view of the editor, referred to as *lateral side view*, i.e., the virtual camera is steered to that wall in order to afford a side view. Furthermore, also the *orthogonal wall view* depicted in the lower-middle view focuses on the current wall. Using that view the city planner can add respectively remove or manipulate windows or doors, and he can assign corresponding textures to them. The *hierarchical structure view* in the upper-right view allows a visualization of the stories in a hierarchical visualization ordered by stories. The *property view* in the lower-right shows further information about particular parts of the building such as windows or walls.

After finishing the generation of a virtual building, it can be stored and imported into a virtual 3D city model. Once generated virtual buildings can be stored in a virtual building library that can be accessed in each new development plan.

3.2 Interaction with Multiple Views

In the next subsections we will explain how certain interaction concepts are realized within the views and how these interactions are coupled respectively de-coupled in order to provide an efficient user interface.

3.2.1 Contextual 3D Preview

The conceptual 3D preview (see Figure 2 (upper-left)) of the editor provides city planners with a three-dimensional preview of the building, which shows its integration into the surrounding. The virtual camera in this preview uses a focus-based approach such that all mouse-based navigation manipulates the virtual camera in a way that the city planner can move around the building, he can zoom in and out, whereas the building always stays in the focus of the virtual camera. The toolbar allows to switch between different visualizations, e.g., realistic rendering as shown in Figure 2 (upper-left), NPR visualization as illustrated in Figure 2 (upper-middle) etc. Furthermore, development plan information, aerial photographs as well as textures can be switched off or they can be attached to the 3D model. By default interactions performed in the 3D preview have no influence on the other previews, i.e., interactions performed in this view are de-coupled from the other views. This enables the planner to review the building process without affecting the other views where modifications are performed currently. However, the user can link this view to other views such that camera motions performed in this view are also applied to the other views.

3.2.2 Vector-based Topview

The vector-based topview on the lower-left of Figure 2 shows the building footprints of each story of a building entity. The city planner can modify the position of each vertex by a simple drag and drop mechanism. The development plan can overlay the grid such that city planners comprehend the restrictions concerning the manipulation process. By overlaying the development plan onto this view, the city planner gets visual information about the constraints that impose buildings, which are located into the corresponding parcel boundary area. For example, the transparent light-colored blue area shows a building area, where the building entity has to be placed in. Furthermore, constraint-based interaction concepts prevent not allowed operations, e.g., vertices can not be moved outside the parcel area.

This view is tightly coupled to the other views. During modifying the vertices of the building footprints other views are updated accordingly. When the city planner selects a wall as illustrated for the wall at the upper right, the active wall is marked in this view and the camera steers automatically to that wall in the lateral view, where it is handled as active wall as described in Section 3.2.3. Since a smooth motion of the virtual camera is used for the steering process, the city planner comprehends the relation between these views immediately.

3.2.3 Lateral View

Similar to the contextual 3D preview, the lateral view enables a three-dimensional preview of the building entity; in particular it allows an evaluation of a selected wall within a certain story. After the city planner has selected a wall of the building entity, for example via the vector-based topview, the virtual camera initiates a motion process, which results in a steered view to that wall. To draw the city planner's attention to the selected story and the selected wall, a frame is displayed around the wall's edges and around the entire story's bounding box. Although initially the camera is focused on one wall, the city planner can modify the camera in terms of rotation around or lifting along the height axis in order to access another wall manually. The view can be focused to another wall by using mouse-based picking techniques to select a desired wall in this view. Further camera modifications are prevented in this view in order to prevent an overstraining of the city planner resulting from complex exploration techniques. The visualization can be altered in the same way as for the contextual 3D preview. A wall in the focus of this 3D lateral view will also be loaded into the orthogonal wall view, described in the next subsection.

3.2.4 Orthogonal Wall View

The orthogonal wall view is tightly coupled to the vector-based topview as well as to the lateral view described in the previous subsections. The active wall in the focus of the lateral view is displayed as two-dimensional facet into this view. The city planner can associate textures to this wall, e.g., to change the construction material such as bricks, wood or plaster. Moreover, he can arrange windows and doors by clamping them onto the wall by means of using direct interaction strategies with the mouse. The visual modifications performed in this window are transferred to the 3D preview as well as to the lateral view, which results in tight coupling.

3.2.5 Hierarchical Structure View

This structured view at the upper-right of the multiple view system visualizes the building entity, in particular its stories, in a textual hierarchical structure; the order is defined by the stories. This view is primarily used to add respectively remove further stories, or to access them in corresponding other views. For example, if the city planner selects a story within this structure, the story will also be in the focus of the lateral view as well as the vector-based topview and the orthogonal wall view.

3.2.6 Property View

The property view enables the city planner to associate textual or numerical values to each entity of a building. Thereby, city planners can determine the height of a story or they can assign house numbers or comments to a building, which can be used, for example, for annotation purposes. Furthermore, all values definable via the previously described views can be entered in a discrete way in order to support exact inputs, e.g., to specify the vertex positions of the building footprints in Gauß=Krüger coordinates.

4 Preliminary Usability Study

Our cooperation partners, in particular the land surveying and land registry office, have evaluated a pre-version of the proposed building editor concepts. As the version introduced in this paper, the pre-version was also based on multiple view system strategies. However, it lacked many features that are supported by the current version. Many of these functionalities have been integrated during and after the evaluation phase of the cooperation partners. These functions include snapping processes when modifying the vertices of the building footprints and the support of overlaying this 2D data with a development plan to incorporate constraints imposed by the development plan. In addition, visualization techniques that enable different levels of abstraction that are specifiable for each preview have been integrated.

Hence, we have tested the current version proposed in this paper in a further usability study in which 8 users have participated. The 7 male and 1 female participants are students of geoinformatics (1) and computer science (4) as well as research assistants (2), which are familiar with city planning tasks. In this preliminary usability study the objective was to evaluate whether and how users exploit multiple views when generating a virtual building. We provided the participants with a standard desktop environment, i.e., 19” display in combination with a 2D mouse and a keyboard. In the next both subsection we propose the test setup and the results of this user study.

4.1 Task

We provided the participants with a test environment in which they had to rebuild simple virtual buildings such as illustrated in Figure 1 (c), whereas the degree of complexity varied for each building. The buildings were classified into simple and into complex buildings with respect to the number of vertices per story as well as the number of floors, i.e., a building consisting of at least two floors and with at least six vertices that define the footprints of the first floor is classified as a complex building, whereas a building with equal or less number of floors respectively vertices is classified as simple building.

Based upon three dimensional visualizations that illustrate the target building entities from different views, the participants had to generate the corresponding building both using a two-dimensional CAD system as well as using our proposed multiple view building editor system. The visualizations of the 3D target buildings were available to the participants during the entire building process. A screen capturing software recorded the proceedings of the users. Thus, a review to analyze the generation processes has been possible.

We have evaluated the accuracy of reproduced buildings in terms of equality with the target building and we have measured the required time using both systems, i.e., 2D CAD and the proposed multiple view system. Furthermore, we have measured the time and number of relevant actions performed in each subview.

Since the task was simplified to the reproduction of a given virtual building, neither aesthetic nor design tasks had to be accomplished by the participants, which would definitely benefit from 3D previews. Furthermore, no constraints regarding neighborhood information or constraints imposed by the development plan had to be considered by the users. Hence, in the tested planning environment there was no need for a multiple view system, i.e., all tasks could be accomplished in 2D very efficiently. However, we wanted to evaluate whether and how the adding of the described views affects such tasks typically performed in 2D.

4.2 Results

The main result of the user study indicates that with an increasing complexity of the target buildings the usage of multiple views gets more beneficial, although the tasks were constrained to a simple reproduction of a given building. However, the study pointed out that the required time to perform the generation process was less using ordinary 2D CAD approaches. As illustrated in Figure 3 the required time to reproduce a simple building averages to 167 seconds when using a 2D system in comparison to 215

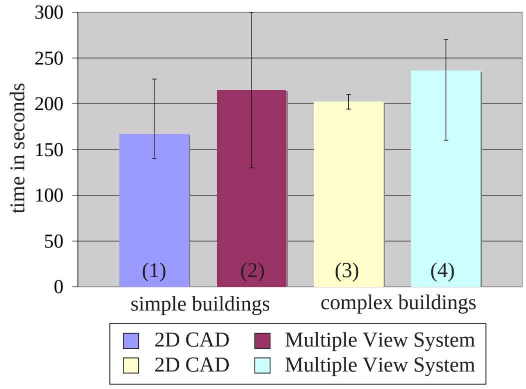


Figure 3: Required time for the generation of simple buildings using the 2D CAD system (1) respectively the proposed multiple view system (2) and for the generation of complex buildings using 2D CAD concepts (3) respectively the multiple view system (4).

seconds when using the multiple view system. For more complex buildings the required time to perform the generation task averages to 202 seconds when using 2D CAD strategies, whereas when using the proposed multiple view system the task requires 236 seconds in average.

Based on observations of the participants during the test, this is due to the fact that when using the 2D view only, the users seem to be more focussed on the objective. When the participants use a straightforward way, for example, by successively handling the building walls and floors to arrange windows and doors, without considering the result, this task can be accomplished very fast in particular in two dimensions. However, this procedure causes errors since the spatial cognition of a 3D representation of the target building to a 2D topview is more difficult than comparing two visual representations defined with the same dimensionality. When additional 3D previews are provided the immediate visual feedback attracts the users attention and the user checks performed steps before proceeding

Hence, the usage of additional 3D preview results in a higher accuracy when accomplishing certain tasks. This issue is also reflected in the user study. When using the multiple view system, each generated building was built correctly in terms of building footprints, position of walls and doors, number of stories and roof types etc. In contrast, the participants made faults when using only the 2D CAD system, i.e., one users chooses the wrong roof type, two users misarranged doors and windows to the walls.

Furthermore, Figure 3 indicates that with an increasing complexity of the target building the performance loss resulting from the usage of multiple view system decreases. While for simple buildings the performance loss when using a multiple view system is more than 22%, the performance loss decrease to less than 15% when generating more complex buildings; although the difference between both types of buildings was marginal, e.g., specifying the building footprints of the complex buildings requires only two further vertices. Therefore, we assume that for more complicated buildings, which, for example, consist of several stories with complex polygonal footprints, the usage of the proposed multiple view system will increase the performance. Moreover, in particular design tasks, which have been ignored in this user study, benefit from the usage of multiple view systems because the user gets immediate visual feedback by means of 3D previews. Hence, an extension of the described usability study that incorporates such issues will underline further advantageous of the proposed system.

5 Conclusions and Future Directions

In this paper we presented a multiple view system for the generation and manipulation of virtual buildings. The usage of the described coupled as well as de-coupled interaction concepts has shown the potential for the city planning domain. Preliminary tests have indicated that the modeling process of building entities can be performed more accurately and therefore more efficient in comparison to the usage of ordinary 2D procedures. However, for simple building entities ordinary 2D CAD systems seem to be more advantageous.

Currently, the land surveying and land registry office evaluate the proposed version of the multiple view building editor system and the urban development, city planning and transport planning office will test the application in a real planning process soon. When these field studies are finished, modifications of the current system and integration of further functionality will be accomplished. Among others these functions will include an automatic feature extraction from images used for texturing walls. For example, from images, which have been taken with a digital camera, windows and doors shall be extracted in order to generate according geometry that can be modified thereupon. Furthermore, we plan to perform another usability study in which also design aspects and constraints imposed by development plans have to be incorporated.

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