Supporting Conceptual Design in Collaborative Virtual Environments

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Abstract

The paper is concerned with the support of conceptual design activities in collaborative virtual environments. It proposes a new understanding of conceptual design from a social perspective that explains the levels of support that are needed / required for this type of CVEs and presents the development of a particular CVE that supports conceptual design in the area of interior space design. It is envisaged that the proposed approach can be employed to provide insight to designers of CVEs for conceptual design about the types of activities that could/should be supported by the tools; guide the selection and/or development of new collaborative tools for CVEs for conceptual design; inform the evaluation of CVEs for conceptual design in terms of the level of support that is achieved for the social activities of concern.

Keywords: Collaborative virtual environments, conceptual design, theory of social (communicative) action, interior space design, virtual reality.

1. Introduction and background

Conceptual design refers to the activities that occur at the first stages of the product lifecycle. Austin et al (2001) explain conceptual design as a vibrant, creative and dynamic process at the kick-off of any design project that can be defined in terms of twelve phases starting from the identification of business needs and functional requirements and ending at the selection of a design alternative for which basic production details and cost options are understood. Conceptual design is an iterative and incremental process; Gero (1998) remarks that '*in conceptual designing not all that is needed to be known to complete a design is known at the outset, i.e. part of the process of designing involves finding/determining what is needed*'. Conceptual design is essentially a collaborative process including designers (usually multidisciplinary designer teams), clients and possibly other design participants and it is considered the most critical phase of product design (Wang et al, 2002). Decisions made at this phase determine the rest of product development and any unintended mistakes, misconceptions and omissions have significant negative impact to the project.

Over the last few years Collaborative Virtual Environments (CVEs) (Churchill and Showdon, 1998) have been used as a tool to support conceptual design. CVEs are based on the concept of "shared space", in which users are collocated as embodiments: 3D representations of themselves (often referenced as 'avatars') that denote their position and orientation in the environment, as well as the activity they are currently performing. The advanced interaction and visualization capabilities offered by CVEs point out their importance as tools for supporting conceptual design. The design of CVEs for the support of conceptual design is a challenging task. Current collaborative design systems offer limited support for conceptual design and mainly support the detailed design and production phases (Wang et al, 2002). In addition current systems for the support of conceptual design lack the necessary theoretical grounding for guiding the systems' designers.

To address these concerns, the paper formulates into a social activity approach for the design and evaluation of CVEs for supporting conceptual design: the knowledge obtained about the conceptual design process (in terms of interviews with interior space designers) and the broad set of tools specific to CVEs that can be employed for this purpose. In addition it illustrates the development of a CVE that demonstrates the usefulness of the proposed approach in the area of interior space design.

The paper adopts and applies the theory of communicative action (also referred as theory of social action - TSA) for the design of conceptual design support systems. The TSA is a comprehensive critical theory of social reality from a communication theoretical perspective that has been developed by the German philosopher Jurgen Habermas (1987). Ngwenyama and Lyytinen (1997) have operationalised the TSA into a framework that outlines a set of social action categories and the rules and resources needed to support them in everyday activity. The social action framework assumes, develops and explains 4 basic types of actions that interchangeably occur in society: a) instrumental action, which is goal oriented focusing on the control, manipulation, and transformation of physical artefacts; b) communicative action, which is concerned with achieving and maintaining common understanding among participants in coordinated action; c) discursive action, which is oriented towards developing or restoring the background conditions for collaborative action; and strategic action, which is oriented towards influencing and transforming the strategic decisions of participants or the group. The paper extends the work of Ngwenyama and Lyytinen (1997) by applying the social action framework to a particular problem context: that of design and evaluation of CVEs that support the conceptual design activity.

The paper is structured as follows: section 2 outlines the social activity approach, which views the basic objectives of conceptual design as social activities and outlines a broad set of tools by which these activities can be supported by CVEs. Section 3 presents the development of a particular CVE for the support of conceptual design in the area of interior space design on the basis of the proposed approach. Finally section 4 presents the conclusions and future work.

2. CVEs for conceptual design as social activity spaces

The consideration of CVEs for conceptual design as social activity spaces entails the following assumptions. First, that the activities that occur continuously and interchangeably within a CVE that supports conceptual design can be mapped within the general categories suggested by the TSA. The discussion of conceptual design activities in terms of general social actions provides an indication for the level of complexity of these activities and allows for assessment of the desired outcome. Second, that an initial understanding about the context of these social activities can be reached by posing questions related to a) the objective of the activity and b) the tools that could support the achievement of this objective. The objectives and tools of social activities are fundamental elements of the context that underlies any type of human activity according to activity theory (Engestrom, 1990).

The proposed approach illustrates a considerable number of particular conceptual design activities that can be supported by a variety of tools in CVEs (Table 1). The set of objectives and tools that have been identified can inform the design and evaluation of CVEs that support conceptual design. It is envisaged that the approach can be employed to:

- Provide insight to designers of CVEs for conceptual design about the types of activities that could/should be supported by the tools;
- Guide the selection and/or development of new collaborative tools for CVEs for conceptual design; and
- Inform the evaluation of CVEs for conceptual design in terms of the level of support that is achieved for the social activities of concern.

2.1 Instrumental activities

Instrumental activity is concerned with the control, manipulation, and transformation of physical artefacts. Instrumental activity presupposes that the agent has the essential knowledge of the form and content of these artefacts in order to perform desired actions. In terms of conceptual design, typical objectives of instrumental activities include the introduction, control and manipulation of tangible objects required for design, such as (Table 1): drawing sketches (Do, 2005), filling in the design brief and producing prototypes.

In the context of a CVE, the environment is usually a complex scene consisting of static geometry, dynamic objects, and user embodiments (avatars). Instrumental activities occur when the user is exploring the environment, identifying and interacting with dynamic objects, possibly transforming, synthesizing or analyzing them to create or reconstruct the design concept. Thus, the environment should offer tools to create new forms in 2D or 3D, to insert, copy and delete objects in the environment, to select and apply geometric transformations and to group objects into more complex ones or to ungroup them, and to change their form.

Table 1. *CVEs for conceptual design as social activity spaces*

Essential social activities within conceptual design	**Why is the activity taking place (objective)?**	**By what CVE tools can this activity be supported?**
Instrumental activities Control, manipulation, and transformation of physical artefacts	Introducing, controlling and manipulating tangible design objects such as: ▪ Drawing sketches ▪ Constructing a landscape (e.g. architectural plan) ▪ Filling in the design brief ▪ Producing a prototype (e.g. rapid prototyping) ▪ Creating mock-ups, models and artwork ▪ Orienting tangible resources into the design work space	▪ Create new forms in 2D and/or 3D ▪ Insert, delete, copy objects ▪ Select content, apply geometric transformations ▪ Combine objects, group and ungroup ▪ Change the form of objects, manipulate their geometry and/or material
Communicative activities Achieving and maintaining common understanding among participants engaged in coordinated action	Verbal, written and visual communication among designers and clients about: ▪ Agreeing the basic plan for coordination ▪ Agreeing the basic engineering principles ▪ Adding details to basic design concept(s) ▪ Agreeing on examples and metaphors about concepts and solutions	▪ Use of expressive embodiments ▪ Support for peripheral awareness ▪ Text messages (chat) ▪ Speech ▪ Post annotations inside the environment ▪ Sharing of viewpoints
Discursive activities Developing or restoring the goals and plans for collaborative action	Activities that mainly refer to goal and process orientation such as: ▪ Expressing high-level descriptions of requirements ▪ Introducing ideas ▪ Expressing concerns about the progress and direction of the design ▪ Applying methods for design, e.g. scenario-based: storyboarding ▪ Applying methods for evaluating and validating solutions	▪ Add diagrams and design concepts ▪ Attach annotations to objects or places ▪ Visualize semantic relations between objects and/or places ▪ Support and visualization of various levels of abstraction
Strategic activities Influencing and transforming the behaviour of participants or the group in order to achieve advantage	Influencing the goals of participants in the conceptual design by activities such as: ▪ Negotiating initial conditions for conceptual design ▪ Considering particular design constraints as unavoidable ▪ Imposing access restrictions to tangible objects and resources ▪ Expressing expert opinions	▪ Support of roles that define access rights to resources ▪ Dynamic assignment and manipulation of roles

2.2 Communicative activities

Communicative activity is concerned with pursuing the goals of conceptual design through communication and interaction among design participants. Communicative activity presupposes that a common understanding about the goals and plans of ac-

tions can be achieved. In terms of conceptual design, typical objectives of communicative activities include verbal, written and visual communication among designers and their clients for accomplishing design goals, such as (Table 1): consenting upon a basic plan of coordination and the basic engineering principles, and adding details to basic design concept(s).

A CVE should support conceptual design by providing a multitude of means for communication, ideally without cancelling the metaphor of the shared space (Tromp et al, 2001). Thus, the design of user embodiments is critical. Synchronous communication can be supported by instant text messages visualized in the environment and spatially related to the speaker, or by spatialised audio. The support of asynchronous communication is equally important in a collaborative environment and can be supported by posting text messages or images in shared spaces. Also, emphasis should be put on awareness so as to allow the observation and evaluation of other users' actions, which can be enhanced with the ability to share viewpoints, i.e. to observe the content from another user's point of view.

2.3 Discursive activities

Discursive activity is oriented towards developing or restoring the goals and plans for collaborative action. Discursive activity unfolds through critical debate and argumentation which forms the basis for joint decision making and agreement. Discursive activity presupposes that design participants wish to engage to common goals about the outcome of conceptual design. Typical objectives for discursive activities in conceptual design are related to goal and process orientation, such as (Table 1): expressing high-level descriptions of requirements, introducing ideas, expressing concerns about the progress and direction of the design, applying methods for design and evaluation.

A CVE can support discursive social activities by enhancing the means for collaborative argumentation. The inclusion of personal working spaces and the ability to copy the content of the shared space to the personal and vice versa allow the construction of hypotheses without affecting the progress of the actual object of collaboration. Activities such as confirmation or expression of concerns, about the work progress or the plan of actions, can take place with the aid of tools that let users to quickly evaluate the current concept and comment on it. In a CVE such tools could superimpose diagrams and design concepts on the working environment, visualize semantic associations between elements (e.g. places, objects, embodiments) and attach comments on them. Furthermore, the environment could support and visualize different levels of abstraction for the same concept(s) in order to aid the sharing of ideas and scenarios.

2.4 Strategic activities

Strategic activity is oriented towards influencing and transforming the behaviour of participants or the group in order to achieve advantage. Strategic activity presupposes

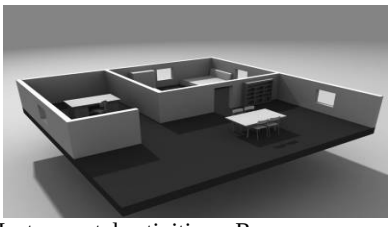
that a design participant or group sets their own goals above the overall objective for design and that they possess the power to negotiate and possibly impose their objective. In terms of conceptual design strategic activities may include negotiating initial conditions for conceptual design (such as budget), considering particular design constraints as unavoidable and expressing expert opinions.

Strategic activities inside a CVE can occur if roles are supported, preferably visualised through the embodiments, and access to environment resources is related to them. In cases where roles need to be flexible, the system may support dynamic assignment of authorities upon resources. In CVEs, such authorities could be visualised in order to be easily identified and/or manipulated inside the virtual space. Up to date, CVEs oriented towards design do not offer inherent support for strategic activities.

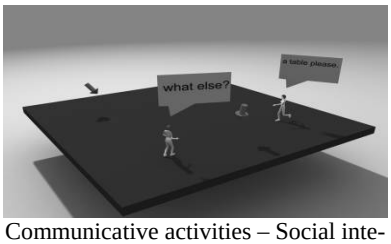
3. A desktop CVE for the support of interior space design

The purpose of interior space design is to enable the clients and designers to conclude to an elaborate proposal about the content of any type of interior space. It involves numerous decisions about style, form, content, furniture and other equipment arrangements and so on according to design principles and client preferences related to ergonomics, accessibility and aesthetics.

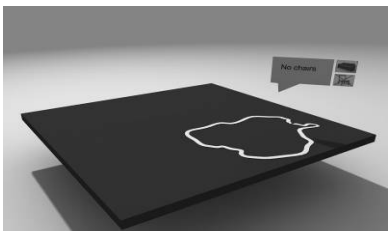
The design approach followed for the development of a CVE for the support of interior space design was based on the social activity space perspective. Our aim was to implement an integrated system with inherent support for the four basic activities. To achieve this, we mapped each activity onto a respective visualisation and interaction space, in which we could focus on the support tools for the particular activity (Fig. 1).



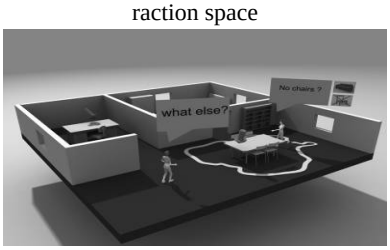
Instrumental activities – Resources space



Communicative activities – Social interaction space



Discursive activities – Requirements space



All social activities – CVE work space

Figure 1. *Mapping social activities into CVE work spaces*

Concerning instrumental activity, we designed the basic interaction space with tools for creating and manipulating content, the *resources space.* We have identified the main instrumental activities that take place in the interior space planning process as: constructing the apartment or room, furnishing it, and examining/exploring the concept. The tools to support these activities in the resources space are:

- *Construction of apartment/room*: construction and manipulation of walls, insertion of doors and windows on walls, insertion and modification of lights, modification of materials (colours, textures) on walls, floor and ceiling
- *Furnishing*: insertion and manipulation of furniture, grouping / ungrouping, alignment
- *Navigation*: exterior view / examination, inside view

The *social interaction space* visualizes all communicative activities. It contains the user embodiments and the messages they send to each other. Concerning user representations, users are expected to spend most of the time using the system in exterior view (Fig. 2a) in which case a human-like representation is not adequate. We employed the solution of tele-pointers (3D arrows denoting the position of a user's mouse pointer) to enhance awareness about other users' activities. When users are navigating inside the environment, they are represented with a human-like model. Concerning communication, the system supports instant messages, message boards for offline communication and the ability to share viewpoints.

The space we designed for discursive activities to take place in is the *requirements space*. In the case on interior space planning, client and designer will need to discuss about the design requirements and to relate them to the actual design concept. Clients may express requirements or concerns to designer(s), while designer(s) may propose new ideas or further analyse the concepts. Finally both may wish to evaluate the generated concepts against the initial requirements. In this space, users can express, visualize and manipulate their requirements, as well as relate them to the objects of the resources space. The tools designed to support user activities are:

- *Expression of requirements*: users may draw/indicate areas on the floor and post annotations on them, e.g. express their needs concerning the functionality of that area. Furthermore, they may use icons or images in order to visualise the type of furniture that they wish to be included or excluded within that area.
- *Expression of concerns*: the system allows attachment of annotations on existing furniture or groups of furniture.
- *Proposition of ideas*: users may draw shapes and regions related to existing furniture. Any transformation on furniture affects the respective annotations and sketches as well. Also, semantic associations (visualised as lines that connect them) may be inserted on two or more furniture to draw attention on them.
- *Evaluation of concept*: the concurrent visualisation of requirements and resources space aids the rapid visual comparison of the existing concept to the expressed user needs.

The strategic activities of conceptual design are supported by the assignments of roles of design participants to the CVE. The basic roles supported are those of the client and the designer. Each role can exercise access rights to the resources they own in terms of locking their position and orientation as well as by allowing others to collaborate with them in the same workspace. We find that there is no need for the development of more elaborated strategic activities, such as support for formal means for decision making, for the particular application of interior space design.

3.1. System overview and use case

The implemented system contains an integrated desktop 3D environment that includes all the aforementioned functionality. We present a typical scenario to demonstrate the use of the CVE for interior space design.

Initially, the clients log-in to the CVE and construct their house according to the architectural plan, which is scanned and mapped on the ground to assist the process. Then, the clients express their basic requirements about the way they would like their home to be designed. They mark areas inside the house where they explain their preferred properties or function by posting annotations; they also visualise their wishes by using include and exclude lists: icons that display types of furniture (Fig.2a). The design team is informed about client requirements expressed in the 3D space and coordinates its work by specifying areas and elements of the environment and assigning responsibilities to the members. They create concepts on the basic of types of furniture according to the client requirements (Fig.2a) and also make new proposals and discuss about the requirements using chat or manipulating the requirements space.

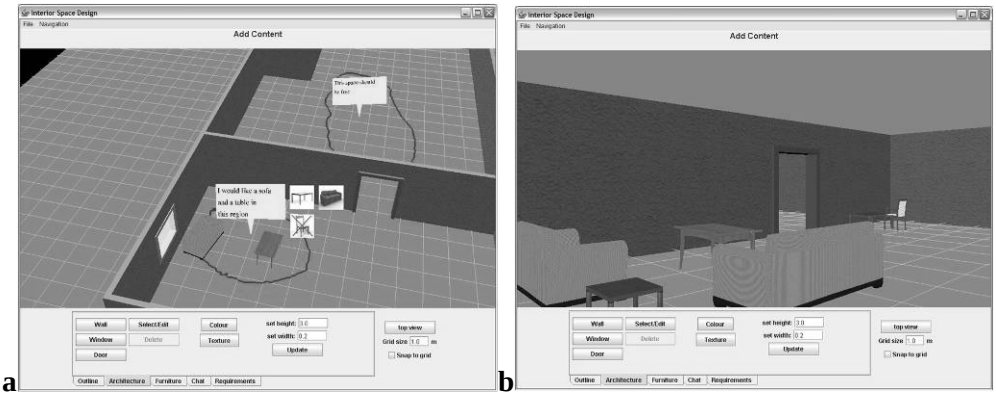


Figure 2.a.*visualizing requirements (exterior view) and* ***b.*** *evaluating a concept*

The clients review the concepts and provide comments on specific aspects of the design using annotations. They navigate inside the environment to evaluate the concepts and they ask for clarifications and possibly express concerns about them (Fig.2b)

asynchronously. They can also arrange meetings inside the 3D environment with the designers.

3.2. Related Applications

The system presented in (Lin et al, 2006) is a multi-user 3D environment for interior design over the Web. However, collaboration is limited to a chat environment external to the 3D space. There is neither support for awareness nor for the discursive activities that may take place during the conceptual design process. A virtual environment for conceptual design in architecture is presented in Anderson et al (2003). Besides the tools for creating and manipulating geometry, the environment supports the insertion of images and videos that can be copied and attached to any surface and can be used for "symbolic representation of intention". There is no inherent functionality for sketching and posting annotations inside the 3D environment.

COVID (Stuerzlinger et al, 2006) is an integrated environment for conceptual design, which uses specialised semi-immersive hardware to facilitate collaboration. The environment provides a range of tools for general purpose 3D design and allows designers to work with different levels of abstraction. Collaboration takes place using a unique hardware installation; there is no support for synchronous remote collaboration and, therefore, all discursive activities happen outside the 3D environment. Finally, Immersive Redliner (Jung and Do, 2000) is an approach towards the support of discursive activities for collaborative design, as it enables the attachment of annotations on models in a 3D scene. The functionality of the system is limited to posting of comments; there are no further tools for communicating ideas, such as sketching.

The discussion above exhibits several advantages of the developed CVE over related application, as it provides an integrated environment to support synchronous and asynchronous collaboration in interior space design, with respect to the discursive activities that take place during the design process.

4. Conclusions and future work

The paper presented a social activity approach for the design and evaluation of CVEs for supporting conceptual design and outlined the development of a CVE for the area of interior space design. The CVE presented allows for remote collaboration of designers and users on a shared virtual workspace, where various resources can be loaded and placed. The most innovative aspect of the CVE is that it addresses - to some extent at least - discursive activities of conceptual design such as providing abstract requirements to particular areas of the work space (building), adding annotations and comments and including/excluding features of interior space. The CVE is not yet fully developed and evaluated. Future work includes: development of interaction techniques for the support of discursive conceptual design, further development

of awareness mechanisms, integration with commercial CAD (Computer Aided Design) systems and user centred evaluation.

We envisage that the theoretical grounding of this work can provide insight to designers and users of CVEs for conceptual design in terms of design and evaluation. However, we acknowledge that the categories of social action are not always clearly defined and distinguished. For instance instrumental action is pertinent in design activities while communicative and discursive actions are not perhaps clearly distinguishable. Also, discursive action is introduced by Habermas as a response to breakdowns in normal activity, while in the case of design activities discursive action is the norm.

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