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Internet-Supported Multi-User Virtual and Physical Prototypes for Architectural Academic Education and Research

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1. Introduction

Even though development of concepts and tools for Internet-based academic research and education may be traced back to the 1960s, only in the last decade concepts such as Internet of Things, Ambient Intelligence (AmI), and ubiquitous computing (ubicomp) have introduced not only a technological but also a conceptual and methodological paradigm shift that implies a general infiltration of Internet-based concepts and tools not only into academic education and research but also into everyday life activities. In this context, Hyperbody at Delft University of Technology (DUT) has been developing in the last decade hardware- and software- prototypes for Internet-supported academic education and research, which were tested in practical experiments implemented mainly in international workshops and lectures. This chapter presents and discusses Hyperbody's past, present and future development and use of software and hardware applications for virtual academic education and research in architectural and urban design within the larger framework of contemporary conceptual, methodological and technological advancements.

2. Concepts and tools

The development of concepts and tools for Internet-based academic research and education such as Engelbart's proposal for using computers in the augmentation of human skills (1962) and Sutherland's Sketchpad as first graphical user interface for computers (1963), the establishment of the Internet (1969) and the development of interactive learning environments enabled universities to offer accredited graduate programs through online courses. While at the time, virtual and physical interaction was separated in corresponding educational programs, in the last decade, concepts such as Internet of Things, Ambient Intelligence (AmI), and ubiquitous computing (ubicomp) have introduced a conceptual and methodological paradigm shift manifested in the blur of boundaries between physical and virtual and the continuous integration of Internet-based concepts and tools into the academic everyday life. In this context, ubiquitous computing refers to the integration of information processing into everyday objects and activities (Weiser, 1988) while the Internet of Things consists of uniquely identifiable (tagged) objects (Things) and their virtual representations inventoried and connected in an Internet-like structure (Ashton, 1999; Magrassi, et al. 2001).

Fig. 1. Protospace: An Internet-based multi-user physical and virtual environment for academic research and education developed by Hyperbody.

Envisioning Ambient Intelligence (AmI) as a physical environment that incorporates digital devices in order to support people in carrying out daily activities by using information and intelligence that is contained within the network connecting these devices (Zelkha et al., 1998), Protospace (http://www.hyperbody.nl/protospace) developed at Hyperbody (Fig. 1) can be seen as an embedded, networked hardware- and software system that is exhibiting characteristics of Ambient Intelligence. This implies that interactive, context aware (sensor-actuator) sub-systems are embedded into the spatial environment in such a way that they are context and user aware by collecting and mapping data with respect to users' movement and behaviour in relation to physical space, they are, when needed, tailored to individual needs, and furthermore, they are adaptive, responding to user and environmental changes, even anticipatory, as for instance, during interactive lectures and workshops described in following sections. Considering that information processing has been, meanwhile, increasingly integrated into physical spaces, everyday objects, human activities (Weiser, 1988) and ubiquitous computing (ubicomp) has become prevalent in everyday life, the following sections aim to critically asses what they offer architectural academic education and research, and thus reveal what challenges remain in their development and application.

3. Methodologies and processes

Late 1990s, Internet-based academic education and research were focusing on education methodologies and applied technologies for educators, students and researchers, who are separated by time and distance, or both (Daniel, 1998; Loutchko et al. 2002). In this context, the requirement for synchronous interaction for participants, who are virtually present at the same time while they are physically remotely located would be implemented via timely synchronous videoconferencing and live streaming, telephone, and web-based VoIP. In addition, participants would access educational and research materials on their own schedule, as well as communicate by means of asynchronous information exchange such as E-mail correspondence, message exchange (forums), audio-video recording and replay.

Other more sophisticated methods would include online three-dimensional (3D) virtual worlds providing synchronous and asynchronous interaction as well as collaboration.

Such systems would, obviously, require high-tech hardware and software equipment and would offer the possibility to flexibly accommodate time and space constraints of users, while reducing the demand on institutional infrastructure such as buildings. Educators, students and researchers attending virtual sessions would exchange and acquire knowledge asynchronously by reading documents from the database or studying videos, for instance, and synchronously by discussing problems, reviewing case studies, or actively participating in workshops. Communication in the synchronous virtual study room is, therefore, conceived as a collaborative study and research experience, where participants are interacting real-time with peers through web-conferencing and 3D gaming.

3D gaming environments inspired, in the last decade, researchers from different disciplines to develop computer-supported collaborative environments such as Protospace in which problem-based studying and researching is implemented. This enables physically and virtually present students and researchers to investigate and solve problems by working in groups, wherein participants identify what they know, what they need to know, and learn how to bridge the gap between the two by searching and accessing information from worldwide available databases that may lead to finding solutions.

In such a context, the role of the instructor, educator, or team leader is that of facilitating the process by suggesting appropriate references, and instigating critical discussions, while open-ended, ill-defined problems, addressed in collaborative group work are driving such a process (Armstrong, 1991). By exploring various strategies in order to understand the nature of the to-be-solved problem, by investigating the constraints and options to its resolution, as well as by acknowledging eventual different viewpoints, participants learn to negotiate between competing, even contradicting resolutions. These approaches implemented in Internet-supported multi-user, collaborative, game-like environments such as Protospace are well suited for addressing architectural and urban planning problems in education and research.

Such approaches are, however, not anymore confined to the classical concepts of the Internet-based education such as distance learning; instead they started to permeate the academic everyday life (Bier, 2011). Internet-based interaction is not anymore employed for distance learning only but it is integrated in the daily interaction, information and knowledge exchange between students, educators and researchers. While learning environments are increasingly accessed in various contexts and situations, ubiquitous increasingly replaces distance learning (Bomsdorf, 2005).

If ubiquitous learning (u-Learning) represents a relevant advancement in the development of distance learning, its obvious potential results from the enhanced possibilities of accessing content and computer-supported collaborative environments at any time and place. Furthermore, u-Learning enables seamless combination of virtual environments and physical spaces and allows embedding individual learning activities in everyday life so that learning activities are freed from schedule and spatial constraints, becoming pervasive and ongoing, prevalent within a large, diverse community consisting of students, educators, social communities, researchers, etc.

4. Applications in education and research

Within the larger context described in the sections before, Hyperbody has been developing in the last decade Internet-supported applications for academic education and research by employing interactive 3D game technology: As an Internet-based, multi-user game environment, Protospace enables real-time collaborative architectural and urban design and has been tested in graduate education and research including the Internet-based postgraduate program, E-Archidoct, that was offered in collaboration with 14 European universities 2008-10.

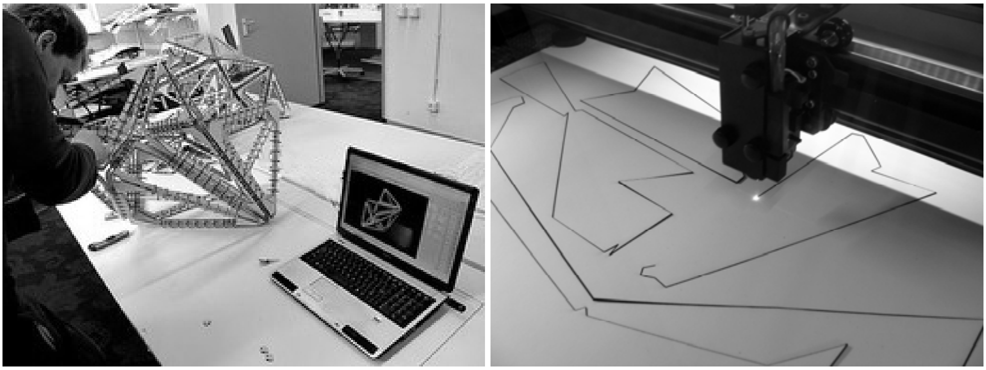

Fig. 2. Rapid seamless CAD-CAM prototyping and CNC fabrication implemented with students in Protospace.

Protospace is, basically, a compound of software and hardware applications for virtual academic education and research equipped with multi-channel immersive audio, multi-screen projection, ubiquitous sensing, wireless input-output devices and (Computer Numerically Controlled) CNC facilities (incorporating a laser cutter and a large mill). It facilitates Internet-supported collaborative design and development of interactive architectural components, supports seamless (Computer-Aided Design and Manufacturing) CAD-CAM workflows, as well as enables implementation of non-standard, complex geometries (Fig. 2) into architecture.

Protospace incorporates, therefore, virtual drafting and modeling as well as physical prototyping tools with shared database capabilities so that changes made by design team members are visible to all other team members, thus allowing for design, evaluation, and dialogue between team members to take place concurrently in real-time. Team members are physically and/or virtually participating in a seamless process of design, prototyping, and review establishing a feedback loop between conceptualization and production.

4.1 Software and hardware prototypes

In addition to CNC machines allowing for CAD-CAM production of 1:1 or scaled architectural prototypes, Protospace incorporates Virtual Reality (VR) hardware and software (Fig. 3) devices enabling implementation of specific tasks such as geometrical and behavioral manipulation.

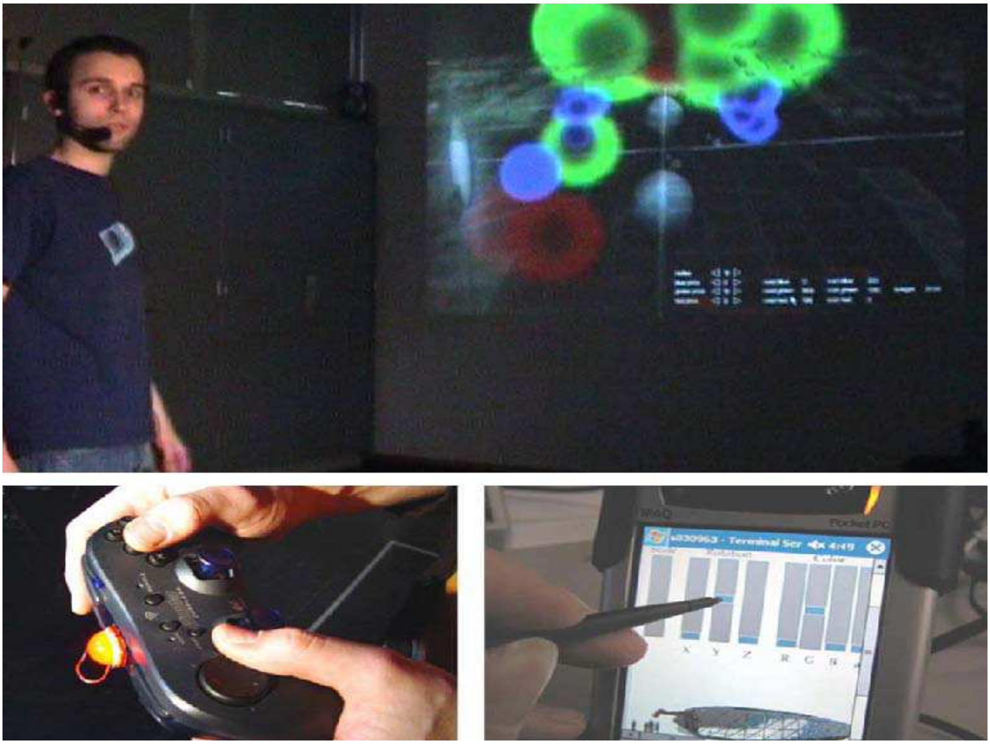

Fig. 3. Protospace: Wireless devices with varying characteristics are available as input devices for implementing specific tasks such as geometrical and behavioral manipulation.

4.1.1 CAD-CAM processes

Internet-supported collaborative processes such as CAD-CAM design and fabrication workflows are implemented in Protospace by means of commercial and non-commercial software applications that in part are developed from scratch at Hyperbody. For architectural and urban design Hyperbody employs parametric software such as Virtools, Max MSP, Rhino-Grasshopper and Generative Components. These CAD applications are coupled with CAM facilities in order to allow seamless production of physical prototypes from virtual models.

With respect to their use in education, in case of E-Archidoct, for instance, in addition to the Internet-based individual and collaborative exchange between students and teachers facilitated by the open-source Modular Object-Oriented Dynamic Learning Environment (Moodle) which was incorporated into the E-Archidoct website, Protospace software applications were as well integrated.

Students were, basically, introduced to parametric software such as Virtools, Grasshopper and Generative Components employed in architectural and urban design projects. Liu's project (Fig. 4), for instance, applies parametric definition for the development of multiple designs. Parametric manipulation implied, among others, the use of the marching cubes algorithm, which constructs surfaces from numerical values; furthermore, programmatic considerations were parametrically defined with respect to function in relation to volume and orientation in 3D space, etc. CAD structural analysis employing MIDAS/Gen implied that data with respect to forces, moments and stresses was used in order to determine the placement and dimension of main and secondary structure, whereas final design was physically prototyped by means of CAM.

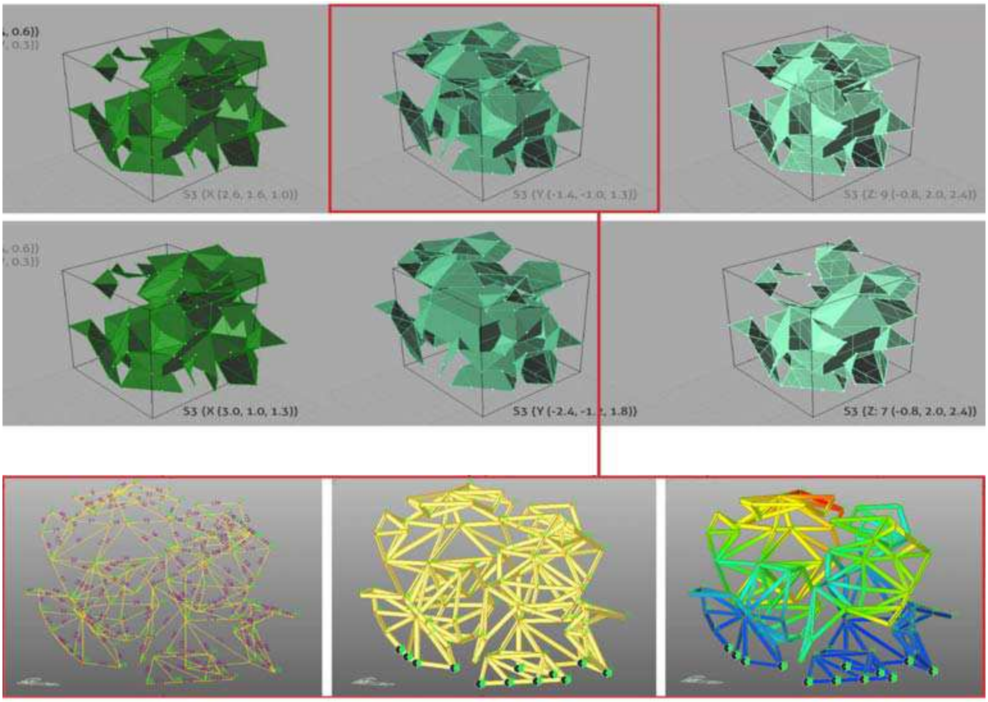

Fig. 4. Liu's project showing multiple design and evaluation phases employing design and structural engineering software.

In addition to CAD-CAM processes in which designers (tutors, students and researchers) may partake physically or virtually, Protospace facilitates interactive presentations that allow physically and virtually present audience to attend and interact with the presenters and their presentations in real-time.

4.1.2 Interactive lectures

Non-linear screen presentations are set-up on multiple screens and non-linear talks follow a paradigm in which the audience is enabled to select from predefined content clusters specific topics, images, and/or movies, which the speaker then presents and discusses.

Following principles of Ambient Intelligence some of the multiple screen projections may be influenced by the audience: The physically present audience can alter the course of the presentation by using laser pointers, or triggering light- and/or pressure-sensors integrated in floor and walls, while audience from all over the world follows and interacts with the presentation via Internet-based interfaces (Fig. 5). In this context, distinct clusters of content are marked with keywords, indicating when audience input is expected or required, while physically and virtually present lecturers introduce and discuss content by means of multimedia and videoconference presentations.

Fig. 5. Interactive presentations with Marcos Novak from University of California in Protospace at TU Delft (iWEB, 2006-07).

4.1.3 Multi-user (3D) games

As one of the most relevant Protospace applications, Virtools allows development of Internet-supported, multi-user (3D) games. Known as *serious games* (Zyda, 2005) such games have a primary purpose other than entertainment as they are designed for the purpose of solving an architectural or urban design problem. They are accessible via a game interface on the Internet by multiple users that can interact with the virtual environment in real-time. Their development in Virtools is based on the separation of objects, data and behaviors, employing an intuitive user interface with real-time visualization window and graphical programming. This allows programming with spatial arrangements of text and graphic symbols, whereas screen objects are treated as entities that can be connected with lines, which represent relations (Fig. 6).

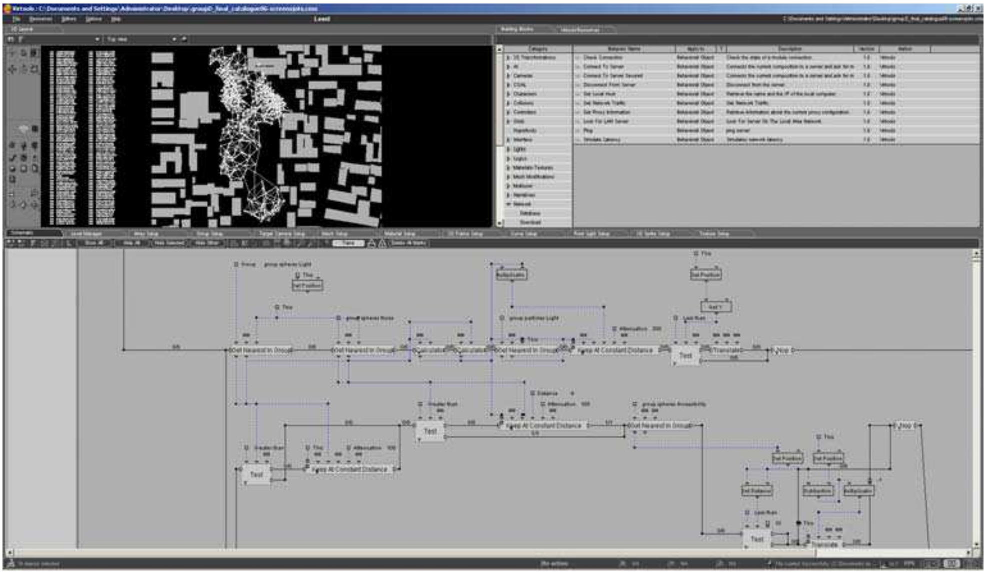

Fig. 6. Hsiao's Virtools script showing graphical programming interface and behaviour set-up for urban design simulations.

Virtools' behavior engine runs both custom and out-of-the-box behaviors, whereas behaviors relevant for architectural and urban design at Hyperbody are swarm behaviors relying on principles of self-organization (Reynolds 1987; Oosterhuis et. al. 2004). Swarm behaviors are collective behaviors exhibited by natural or artificial agents, which aggregate together, exhibiting motion patterns at group level (Mach & Schweitzer, 2003). These behaviors are emergent, arising from simple rules that are followed by individuals (agents).

Protospace applications such as Virtual Operation Room (VOR), Building Relations (BR) employ swarm behaviors in order to address issues such as interactivity in architecture (Bier et al. 2006) and automated placement of programmatic units in 3D space either at city or at building scale (Bier, 2007).

VOR is, basically, an interactive environment allowing participants to playfully start to understand interactivity principles, which are then applied in design using Protospace's design interface. In order to incorporate behaviors and interactively change geometry in real-time, VOR employs self-organization principles of swarms enabling elements of the structure to respond to external changes. According to Oosterhuis (2006) swarm architecture implies that all building components operate like intelligent agents, whereas the swarm is, in this context, of special interest: Self-organizing swarms go back to Reynolds' computer program developed in 1986, which simulates flocking behavior of birds. The rules according to which the birds are moving are simple: Maintain a minimum distance to vicinity (1), match velocity with neighbors (2) and move towards the center of the swarm (3). These rules are local establishing the behavior of one member in relationship to its next vicinity.

Similar to Reynolds' flocking rules, VOR's icosahedral geometry employs rules regarding the movement of its vertices. The movements of its vertices are controlled as follows: (1) Keep a certain distance to neighboring vertices; move faster if you are further away. (2) Try to be at a certain distance from your neighbors' neighbors; move faster if you are further away. These rules aim to establish a desired state of equilibrium implying that VOR aims to organize itself into the primary icosahedral structure. Under exterior influences VOR executes geometrical-spatial transformations according to the rule (3): Try to maintain a certain distance to the avatar, whereas the avatar is an embodiment of the user in this multi-user virtual reality (Fig. 7).

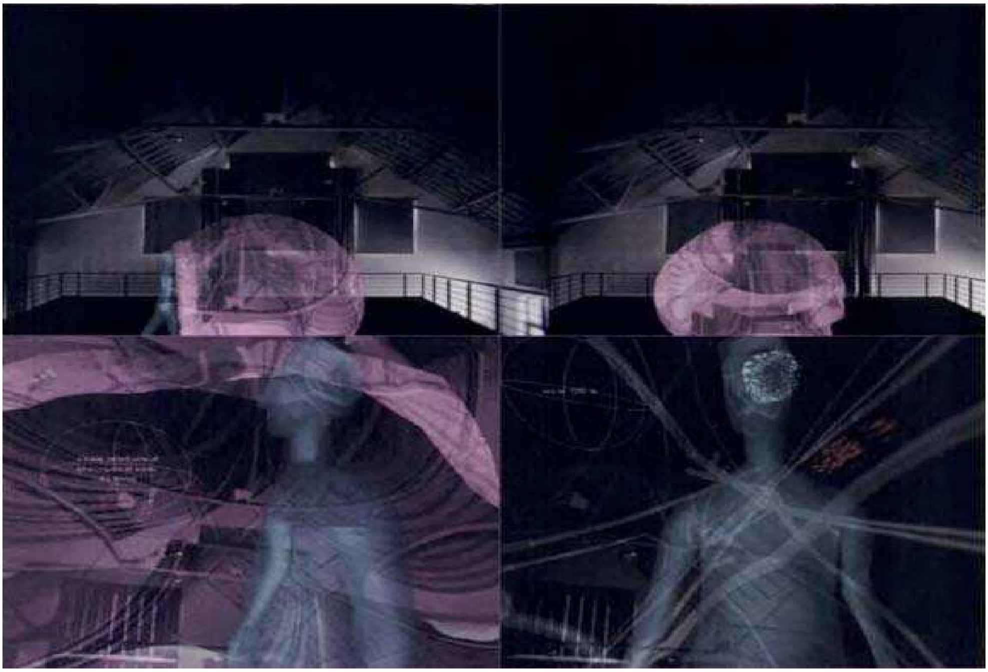

Fig. 7. VOR can be navigated via an avatar that can enter a virtual world represented as an icosahedral structure.

VOR, as a multi-user interactive environment, is a computer simulation of an imaginary system, a game that enables users to perform operations on the simulated system (Oosterhuis et al. 2004) while showing effects in real-time. Basically, VOR consists of responsive environments with which the user interacts via input devices such as mouse, keyboard, and/or joystick; these allow for intuitive maneuver and navigation.

At building scale, applications developed by Hyperbody have been focusing on the development of interactive design tools, which allow simulation of complex design processes such as space allocation: BuildingRelations (BR), for instance, proposed an alternative design method based on swarm behavior.

BR consists of agents interacting locally with one another and with their environment as follows: In the absence of top-down control dictating how individual agents should behave, local interactions between agents lead to the bottom-up emergence of global behavior. Similarly, all functional units pertaining to a building can be seen as flocking agents striving to achieve an optimal spatial layout (Bier et al. 1998; Bier et al. 2006). In this context, spatial relations between functional units can be described as rules, according to which all units organize themselves into targeted spatial configurations (Fig. 8). This approach is particularly suitable for the functional layout of middle large structures: While the architect might find it difficult to have an overview on all functions and their attributed volume and preferential location, functional units can easily swarm towards local optimal configurations.

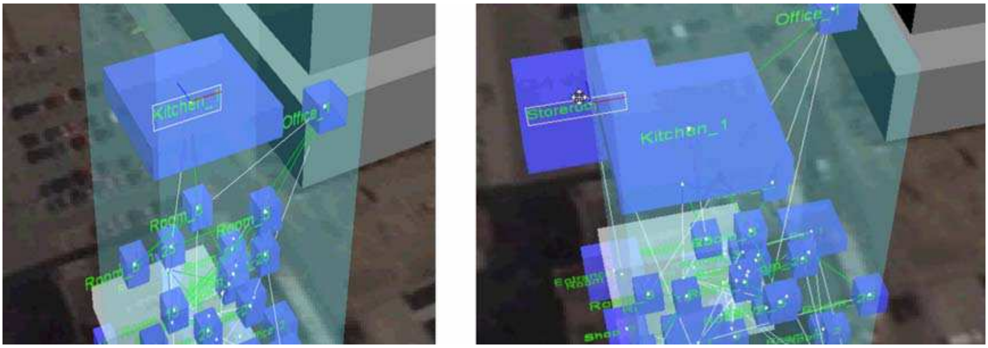

Fig. 8. BR - Architectural design studies implemented in interactive environments developed in Virtools.

Basically, programmatic distribution of functions in architectural design deals with the placement of functions in 3D-space; in this context, building components such as rooms have neither fixed dimensions nor pre-defined positions in space. Attempts to automate the process of layout incorporate approaches to spatial allocation by defining the available space as an orthogonal 2D-grid and use an algorithm to allocate each rectangle of the grid to a particular function. Other strategies break down the problem into parts such as topology and geometry: While topology refers to logical relationships between layout components, geometry refers to position and size of each component of the layout. A topological decision, for instance, that a functional unit is adjacent to another specific functional unit restricts the geometric coordinates of a functional unit relative to another (Michalek et al., 2002; Bier et al. 2007).

Based on a similar strategy BR generates solutions for complex layout problems in an interactive design process. Furthermore, it operates in the 3D-space and therefore, it represents an innovative approach to semi-automated design processes. The BR database establishes connectivities between different software and functions as a parameter pool containing geometric and functional data. BR is being used interactively and in combination with other software, to achieve non-deterministically designs. It is a design support system, since it supports the user (designer) in the functional layout process rather than prescribes a solution.

At urban scale, applications developed by Hyperbody have been addressing space allocation in a similar way BR does: While at building scale spaces are allocated within a building, at urban scale buildings and building clusters are allocated within an urban area (Fig. 9). The allocation principle is, however, the same: Functions and dedicated volumes swarm within the urban context towards local optimal spatial configurations (Jaskiewicz, 2010).

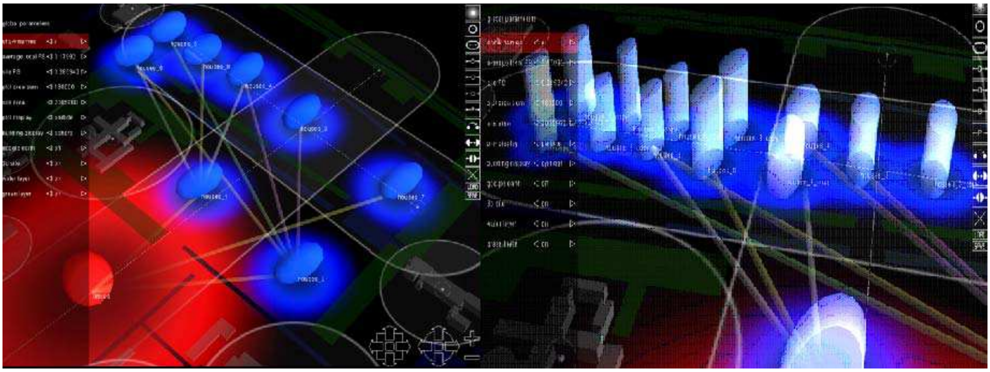

Fig. 9. Urban design studies implemented in interactive environments developed in Virtools.

Obviously, these applications are of interest for Internet-supported education and research as they enable interactive, collaborative, (virtually and physically present) multi-user design and fabrication sessions.

4.2 Users' interaction in education and research

The classical concept of distance learning implemented when time and distance separate educators and students is increasingly replaced by Internet-supported systems that are employed to assist daily academic interaction even when researchers, educators and students are not separated by time or distance. This is the result of a conceptual and methodological paradigm shift that implies an ongoing change towards pervasive computing and ubiquitous education and research as already discussed in the previous sections.

Considering the Internet as the start, Castells extrapolates 1996 the expected development of such a networked system towards becoming pervasive, permeating the everyday life. The purpose of Internet-supported systems is, therefore, not anymore to only bridge time and distance but to support everyday academic education and research by incorporating ubiquitous, interactive devices into the physical space. In this context, Protospace can be seen as a prototype for pervasive computing that is integrated into physical space and is employed in academic daily life, whereas interaction between users and data takes place in a networked, Internet-supported, embedded system.

In such a networked system, users are connected with other users, multimedia databases and applications enabling reading and editing of data, sensing-actuating, and computing in such a way that users interact physically and virtually as needed in a physical, digitally-augmented environment.

By integrating concepts such as Autonomous Control (Uckelmann et al., 2010) the Internet of Things is envisioned as a network in which self-organized virtual and physical agents are able to act and interact autonomously with respect to context and environmental factors. Such context awareness (Gellersen et al., 2000) implies data collection and information exchange thus communication between users and physical environment; it may imply acquisition of data with respect to users' habits, emotions, bodily states, their social interaction, and their regular and spontaneous activities as well as context data with respect to spatial location, infrastructure, available resources, and physical conditions such as noise, light, and temperature. Information exchange thus communication between physical (sentient) environment and users may, however, not only imply accommodating but also challenging interactions.

As a context aware system, Protospace is concerned with the acquisition of context data by means of sensors, as mentioned before, the interpretation of the data collected by sensors, and the triggering of accommodating and challenging actions as response to the interpretation of collected data, whereas responses may imply operation of electrical light, sun shading, and projection screens, depending on local and global needs, etc. Furthermore, Protospace's context awareness addresses also activity recognition as implemented in interactive lectures and CAD-CAM sessions described in the previous sections.

5. Discussion and outlook

The on-going fusion of the physical and the virtual reflected in the convergence of the Internet, mobile communication systems, and advanced human-computer interaction technologies generates a reality-virtuality continuum (Milgram, 1994) containing all possible degrees of real and virtual conditions so that the distinction between reality and virtuality becomes blurred.

In this context, Protospace as a reality-virtuality continuum facilitates not only interactive design and fabrication sessions but also interactive presentations for Internet-based graduate programs (E-Archidoct) becoming a relevant platform for studying and researching by connecting virtually students, educators and researchers from all over the world. This implies that Protospace connects users and data physically and virtually in such a way that activities in academic education and research are enhanced by the inherent use of knowledge, software and hardware applications incorporated into it and the available multiple interaction modes.

As technologies evolve and pervasive forms increasingly emerge, permeating all aspects of academic everyday life, concepts such as distance learning are gradually replaced by ubiquitous education and research implemented in sentient, interactive environments. The traditional divide between formal (physical) and informal (virtual) contexts of education and research is blurred. Technological as well as social, cultural, and institutional changes mean that learning, studying, and researching are possible across spatial and temporal barriers. Internet-supported academic education and research implies thus that the physical environment with integrated, networked, interactive devices such as Protospace incorporates increasingly aspects of context-awareness, adaptation, and anticipation, (Zelkha et al., 1998; Aarts et al., 2001) supporting virtual and physical everyday academic activities.

Such systems may show, however, as in the case of the E-Archidoct program, that only a limited amount of students may participate successfully in such a program. Reasons for this may be found not only in technological requirements but also in methodological constraints; Students and educators from all over Europe participating in E-Archidoct were confronted with one of the main barriers to such virtual collaborative interaction, which is the difficulty in achieving agreement when diverse viewpoints, cultural boundaries, and different working and cognitive learning styles exist (Dirckinck-Holmfeld, 2002).

Furthermore, students' limited access to necessary software and hardware as well as insufficient know-how in dealing with software and hardware was an additional problem: Some design assignments within E-Archidoct, for instance, required software and hardware to which not all students had access. Furthermore, local technical support (for tutors and students) was needed in order to ensure successful participation in the program, this, however, could not always be afforded.

Future developments of virtual and physical systems for Internet-based and –supported education require, therefore, access of all participants to software and hardware as well as development of computer literacy and technology know-how among them. This may be implemented via educating students and researchers with respect to the use of Internet-based facilities before starting specific education and research program but also implies development of user-friendly software.

However, interaction models whether menu-driven or GUI-based (Graphical User Interface) are improving and are increasingly supported by applications such as mobile phones, radio-frequency identification tags, and GPS (Global Positioning System). As these devices grow smaller, more connected and more integrated into spatial environments so that only multimodal user interfaces remain perceivable for users (Aarts et al., 2001), Hyperbody investigates and further develops their use for academic education and research. Protospace, for instance, may operate in the future as physical and virtual laboratory enabling users to even remotely conduct physical experiments from other geographical locations. The benefits of such remote laboratories are known in engineering education (Ferreira et al., 2010) and imply advantages such as: (1) Relaxation of time constraints and 24/7 accessibility; (2) Relaxation of geographical constraints and independence from physical locality of researchers; (3) Material costs reduction due to sharing of lab costs and avoiding start-up costs for new laboratories; (4) Enhanced sharing of knowledge, expertise and experience.

In this context, research and education on architectural and urban design and production may be then implemented with students, educators, and experts from all over the world, interacting virtually and physically by means of multimodal interfaces, collaboratively working in a multi-user, gaming environment, that is enabling them to access and manipulate the same data on a common server synchronously or asynchronously, and even implement remotely CAD-CAM experiments.

The relevant question for the future seems to be, therefore, not whether intelligent, sentient environments may be built, but how these environments may be employed as instruments for enhanced, distributed problem solving (Bowen-James, 1997; Novak, 1997), how ubiquitous education and training may be implement in programs that promote digital democracy and literacy by bridging the digital divide (Norris, 2001), how intelligence may be embed into the physical environment in order to be made available to users.

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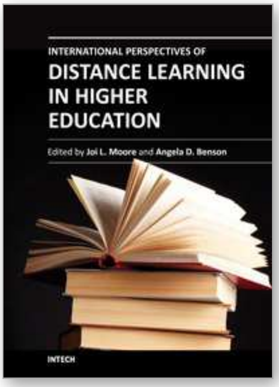

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This book, written by authors representing 12 countries and five continents, is a collection of international perspectives on distance learning and distance learning implementations in higher education. The perspectives are presented in the form of practical case studies of distance learning implementations, research studies on teaching and learning in distance learning environments, and conceptual and theoretical frameworks for designing and developing distance learning tools, courses and programs. The book will appeal to distance learning practitioners, researchers, and higher education administrators. To address the different needs and interests of audience members, the book is organized into five sections: Distance Education Management, Distance Education and Teacher Development, Distance Learning Pedagogy, Distance Learning Students, and Distance Learning Educational Tools.

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