Theme:

Title: **Virtual Reality in the Service of User Participation in Architecture**

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Abstract: *The issue of user participation in the processes of building and urban design is enjoying renewed attention following its relative neglect over the last 20 years due, in large measure, to significant advances in emerging information technologies, particularly multimedia, virtual reality and internet technologies.*

This paper re-established the theoretical framework for participatory design evolved in the late sixties and early seventies as part of the movement towards a more explicit design methodology and attempts an explanation of why the concept failed to gain commitment from the architectural and urban design professionals.

The paper then gives an account of two significant developments in the evolution of the application of information technologies with which the authors have been engaged. These are:

i. a responsive and interactive interface to wholly immersive and realistic virtual reality representations of proposed buildings and urban neighbourhoods.
ii. an intuitive and platform-independent VR modelling environment allowing collaborative evolution of the scheme from within the virtual world.

The impact of these IT developments is demonstrated in the context of the design of a leisure facility for a community of users with physical impairment.

Keywords: *user, design, participation, VR, CAAD, Architecture*

Design Decision Making

Architectural design is a multi-faceted occupation which requires, for its successful performance, a mixture of intuition, craft skills and detailed knowledge of a wide range of practical and theoretical matters. It is a cyclical process in which groups of people work towards a somewhat ill-defined goal in a series of successive approximations. There is no 'correct' method of designing and, although it is recognised that the process can be divided into separate phases, there is no generally accepted sequence of work that might guide design teams in the direction of achieving a satisfactory solution. Indeed, there are no solutions to design problems in the way that there are solutions to mathematical problems: the best that can be hoped for is an outcome which satisfies the maximum number of constraints which bound the area of concern. Furthermore, design is not an algorithmic process in which the desired conclusion can be reached by the application of step-by-step procedures - first finalising this aspect, then that. It is a fluid, holistic process wherein at any stage all the major parts have to be manipulated at once. In this sense, it is less like solving a logical puzzle and more like riding a bicycle, blindfold, whilst juggling.

Despite the complexity of the design decision-making process the emerging new generation of computer-based models is already having an impact on how design is performed and, hence, on the quality of design. The impact stems from the fact that the new models, as opposed to paper-based plans and elevations or other conventional forms, are predictive rather than descriptive; dynamic rather than static; explicit rather than implicit and, above all, permit a more-or-less continuous and interactive assessment of the effects of a developing design on cost and performance.

Evidence is growing of the advantages offered by the application of computers in design, and these can be summarised as follows:

Widening the Search for Solutions

Access to programs which dynamically predict the cost and performances characteristics of optional design proposals can increase the scope of search for good solutions by as much as ten-fold. Not only is the search coverage extended, it is also more purposefully directed because designers are able to compare the quality of any one tentative solution against the quality of all previous solutions.

Greater Integration in Decision-Making

In conventional working, a great deal of design time is lost as proposals are passed to and fro between the architect (who tends to be the originator) and the other specialist members of the design team (who tend to the "checkers"). Quite frequently the scheme on which the architect has lavished time and effort is found by one or other of the specialists to be infeasible. With access to appropriate appraisal techniques embodied in computer programs, it is possible to check a proposal against a wide range of criteria from the outset of the design activity. Moreover, it is entirely practical (though not yet a widespread working method) for all members of the design team to have access to, and operate on, the common design model whether or not they share a design office. The models, then, can provide a strong integrating force in design team working.

Improving Design Insights

Apart from the use of appraisal programs to search for better designs, the programs can be used in a research and development context to provide insights into the way in which particular design decisions affect cost and performance. Typically, a designer working in this mode would select an existing building for study, then, keeping all other design variables constant (insofar as this is possible), systematically vary one factor while recording the cost/performance output from the program. In this manner, the architect can establish sets of causal relationships which provide powerful insights into structure of design decision-making.

Differentiation of Objective and Subjective Judgements

Contrary to the early fears of many architectural practitioners, the use of CAAD techniques focuses increased attention on subjective value judgements rather than less. As measurable attributes of optional designs are made more explicit, the necessary value judgements are forced to the surface of design activity and thereby, themselves become more explicit. The effect of this is to make it clear to designers and their clients, which judgements are based on quantifiable criteria and which on subjective and intuitive concepts.

Evidence of the degree to which computer-generated cost/performance information promotes effective value judgement, throws into sharp focus the crucial question: **whose** value judgement? This question was, for the first time, seriously addressed in the Design Participation Conference in Manchester in 1971 (1). At that time, however, the human-machine interface was too primitive for the concept of useful participation by the users of buildings to be achieved. The new technologies of VR and Multimedia give real prospects for participation.

Virtual Reality

The present use of 3D simulations or more effective virtual worlds has provided the designer and user participants with new media capable of storing several levels of information traditionally obtained only with the help of multiple media, usually more time and resource-consuming.

Virtual models in particular can store information about planning issues, geometric design, material choices or even furniture and lighting conditions. This level of representation provides the designer with all the necessary tools to represent an architectural environment and facilitate the research of potentially good design solutions.
The use of Virtual Reality (VR) within the design process has not only enabled the designer to store more information than with the use of the traditional media and to check the design solutions more efficiently but furthermore it has enhanced the level of simulation providing:

- **Immersion**: Users are completely surrounded by the environment.
- **Presence**: Being surrounded the participant has actually the sensation of being *in* the environment. The Virtual Environment becomes then a place on its own and its perception is similar to real environments.
- **Interactivity**: This is surely the most important *feature* provided by VR: the environment allows the participant to be involved and the result of the actions done by the participant is visualized in the VE.
- **Autonomy**: Participants are neither constrained in paths nor in views preset by others but have the freedom and autonomy to explore any single part of the environment.
- **Collaboration**: Multiple users are able to take part and to interact in the same VE.

The use of VR can also broaden the boundaries of traditional perception to give the experience of worlds not necessarily real or material and to give the freedom to safely simulate dangerous or expensive condition for training purposes. In fact some applications can simulate something completely different from anything we have ever directly experienced such as the visualisation of the ebb and flow of the world's financial markets or the information of a large corporate database. Other applications provide ways of viewing from an advantageous perspective not possible or too expensive in the real world, like scientific simulators, tele-presence systems and air traffic control systems.

The speed at which technology is evolving is making the application of VR within the design professions a feasible approach. AEC companies have already started to evaluate how time consuming the traditional presentation path can be where animations or walkthroughs are used to show designs solutions to their clients. In fact traditional CAD/CAAD systems are used as rendering tools more than design tools. Any change on design solutions is subject to the inevitable delay of having to step back to the CAD/CAAD systems and then the result must be rendered again to be eventually visualized. This approach is obviously not only inconvenient but time consuming and therefore costly. The consequence of these issues is that some design and manufacturing companies have already started to investigate how VR can be used within the design process.

The JCAD-VR Prototype

In the Department of Architecture and Building Science at the University of Strathclyde, the ABACUS group has been building a prototype design decision support system known as JCAD-VR (2).

The idea upon which the JCAD-VR framework is founded is to anticipate the use of VR within the creation phase thus taking full advantage of VR technology. The system in fact allows the creation of simple virtual environments through a user-friendly interface without forcing the user to model it with traditional CAAD packages. The use of CAAD packages is therefore left to the final stage of the project, where further refinements are needed.
It creates simple parametric 3D-shapes directly in a co-edit VR environment, thus allowing the design to be shared as it evolves.

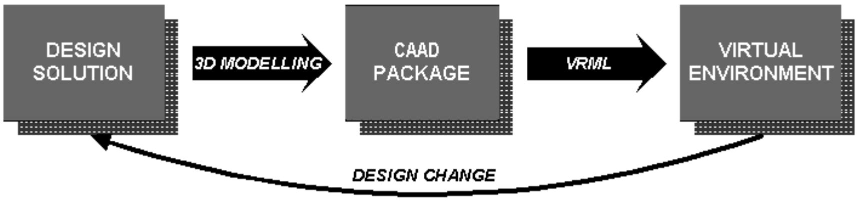

Figure 1. Traditional Schema.

Figure 2. JCAD-VR Schema.

To allow constant collaboration between several users the entire project is based on client-server architecture where every user accesses the virtual world, interacts with the VE and shares design tasks. The whole framework is organised in an object-oriented fashion, where each module fulfils a certain task and it is independently coded. This approach has allowed the delivery of an initial functioning core of the system, whose capabilities will be expanded in the near future.

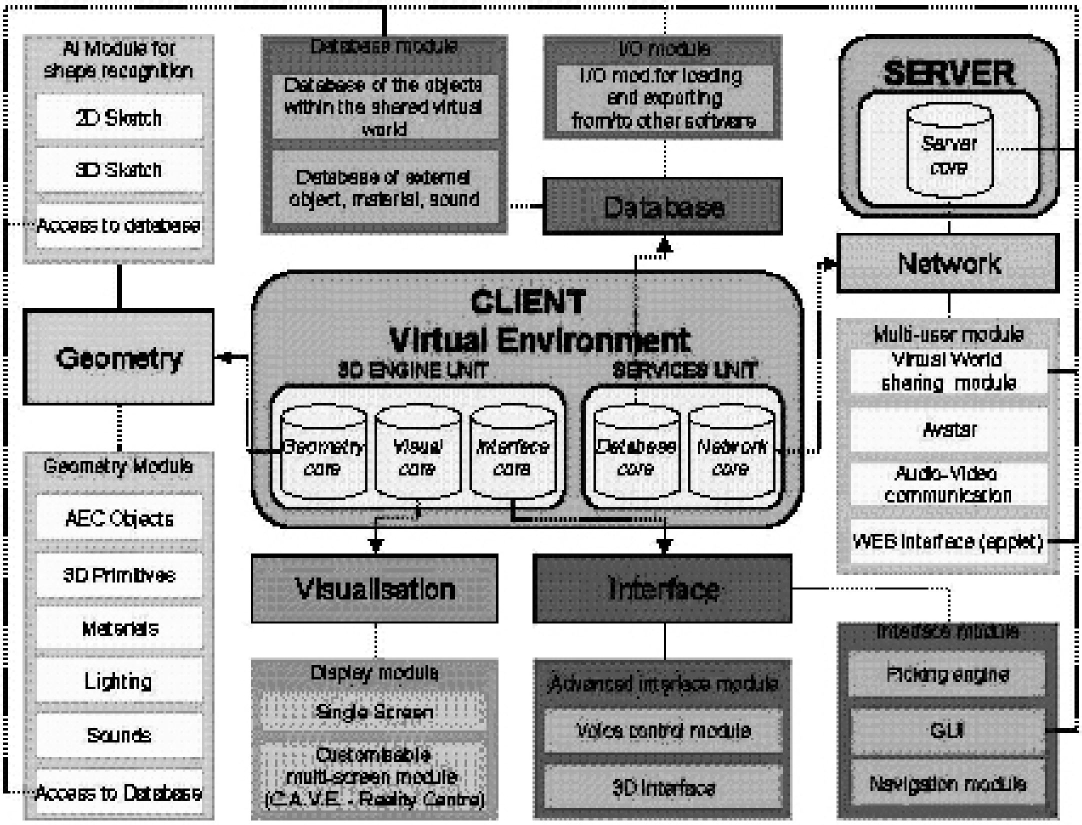

Figure 3. The JCAD-VR framework schema

From the implementation point of view JCAD-VR handles the VE through two closely connected sections: a *3D engine* and a *services unit* each made of several *modules.*

3D engine unit

The 3D engine handles all the information regarding the visual aspects of the VE. It includes the code necessary to create and modify geometric entities (**geometry core**), to run the 3D-interface (**interface core**) and to deal with several different output devices (**visual core**).

The first module of the **geometry core** handles the creation of 3D objects: both geometric primitives (cones, boxes, spheres etc.) and architectural entities (walls, slabs etc.). To the architectural entities some extra properties were provided such as: information on internal and external faces or windows and doors attached to them.
The *geometry module* will also provide the means for attaching materials to objects and add lights and objects from a library to the virtual world through the *database module*.

The **interface core** does not implement a traditional graphic user interface (GUI): JCAD-VR has been provided with a 3D interface that is an integral part of the virtual world itself. The idea behind it is that instead of the traditional menus and toolbars the UI is immersed in VE providing the means for the interaction: 3D menus pop up showing 3D icons and the 3D menus themselves can be moved for the convenience of the user. Visual feedback is provided in the form of rulers showing the size of objects or 3D icons helping the user in the operations to be done on the objects.

The **visual core** is the part of the framework that allows the interfacing with the visualization devices. The client application has been implemented in order to be used on PCs as well as on SGI supercomputers. The former are normal PCs whose video-card is displaying the virtual world only on a traditional window at full screen, the latter is a 12-processors 6Gb Ram SGI Onyx2 system running a Reality Centre. When JCAD-VR is launched on the system running the Reality Centre it can take advantage of the increased computational power stretching its visual output on a 5 metre wide 2 metre high tassellated screen where 3 projectors create a 160 degree panoramic image.
For the sake of flexibility the entire system is coded in Java™. The choice, even if less efficient in terms of performances if compared with some other languages, offered indeed great flexibility, true scalability and last but not least fully multi-platform support. Moreover the use of Java™ programming language became a natural choice when its 3D suite was released (Java3D™).
This choice has provided the flexibility necessary to deliver images for a range of viewing devices and the internal architecture of the visual core is such that modules might be easily adapted to allow use of different VR devices such as CAVEs or Headmounted Displays.

Services unit

The *services unit* handles all the circulation of data within the system.
It is the backbone of the interconnection between users: it manages network connections, it exchanges data between users (**network core**) and it keeps track of the state of the virtual world through a database from which it also retrieves objects information (**database core**).
The *services unit* is based on a client/server architecture therefore it is implemented across two independent packages of the framework the *client* and the *server* and the **network core** allows the transmission of data between them.

The **network core** is thus based on a multi-client server, several clients and the network allowing the communication. The server is the data-delivering unit that looks after the information to be broadcast. The clients are the users themselves who perform actions and queries, when active, and when passive, rely on the server for receiving data update. The intrinsic multiplatform nature of JCAD-VR, inherited from the language used, allows the server to transmit data to a broad range of machines across several operating systems. The communication channel ensures the link between server and clients through a TCP/IP network.
As an independent part of the framework the server has a simple and autonomous interface that provides primarily information about the network system.
At the present stage the *network module* supports:

- Broadcasting of new geometries in the VE
- Notification of creation of new geometries in every user's internal database and broadcasting of their numerical information
- Broadcasting of modifications applied on geometries in the VR scene
- Notification of changes on geometries in every user internal database
- Checking for user priority on the objects through a distributed locking mechanism
- *Avatars* representing multiple clients in the VE
- Interaction between users through a chat system and a whiteboard for freehand sketching in 2D.

It will be soon expanded to include new functionalities such as the transfer of voice and video across users.

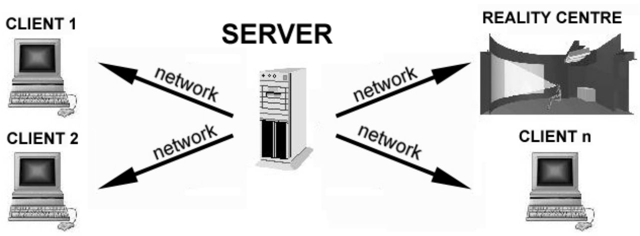

Figure 4. The client/server architecture of JCAD-VR where the server broadcasts to several clients including the Reality Centre

The **database core** includes an internal database, that keeps track of the numerical parameters of the geometries created or modified within the virtual scene, and an external database through which users will be able to retrieve more complex 3D shapes, AEC objects, materials, lights etc.
The internal database is closely coupled with the **network core**. Not only it keeps track of what it is happening in the user's virtual world but also, most importantly, it receives, through the network, information sent by other users' internal databases. If a new object is created or its geometric parameters are changed the system will upgrade the internal database of each user no matter who is doing the action.
For the convenience of the user an *I/O module* supports loading of external files thus allowing import from traditional CAAD packages.

Initial Trials

The current prototype version of JCAD-VR is starting trials of its simultaneous use at the Technical University of Eindhoven and the University of Strathclyde. However, an earlier version was piloted with a group of students in the BSc (Architectural Studies) at the University of Strathclyde.

The brief for the design project associated with the workshop was quite demanding: A Sailing Club for the Disabled located on a canal site in Glasgow City Centre. A real client community agreed to be involved in the project and in the assessment of its outcomes (3).

Within the overall JCAD-VR system, students were encouraged to use initially a standard CAAD package for initial creation of the geometry and then to refine the design using VRML. Event management in their virtual worlds was done through the user of sensors and connectivity. These include touch sensors, proximity sensors, time sensors and anchors.

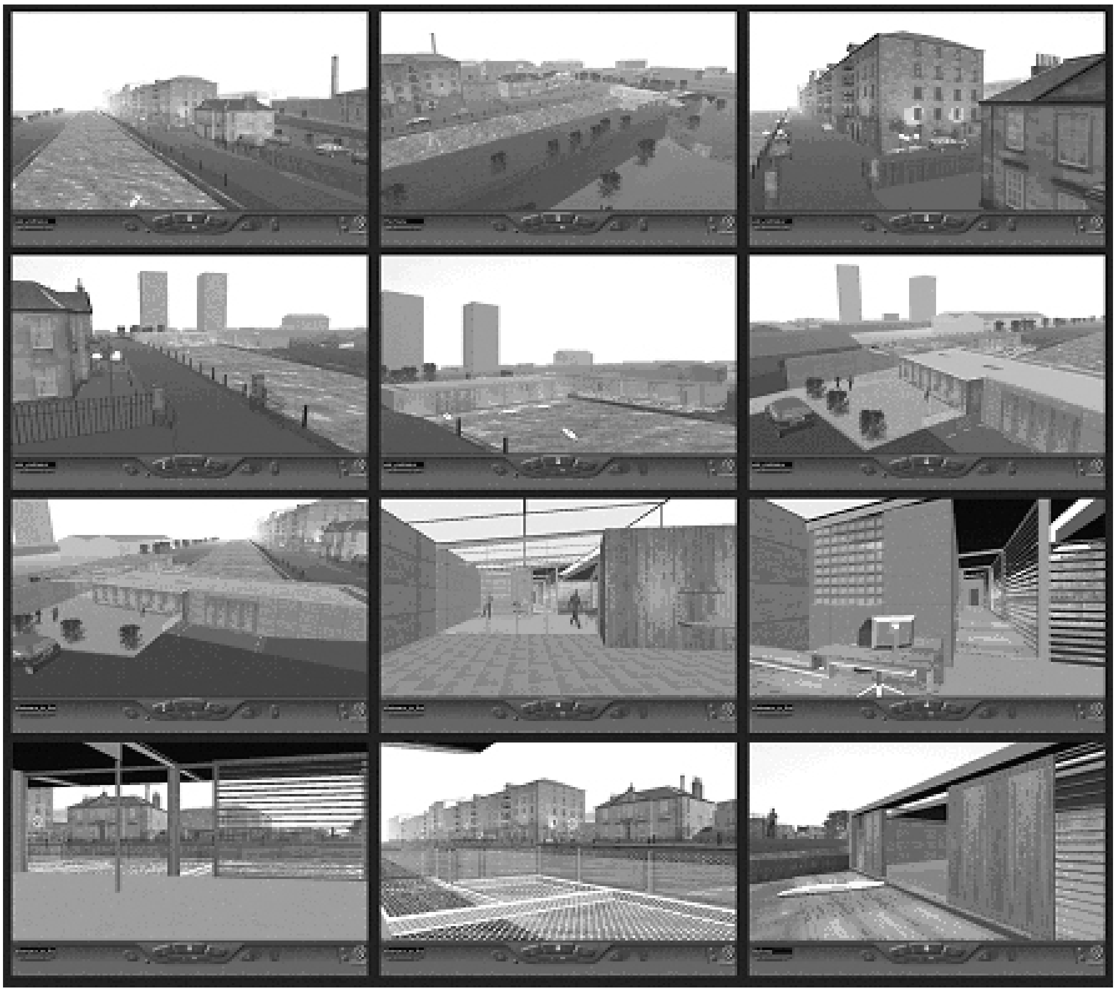

Figure 5. Sailing Club for the Disabled at Spier's Wharf, Glasgow.

The design outcomes

The outcome of the experiment – although not statistically measurable – was nonetheless considered to be remarkable by both the tutors and the client community. One second year student in particular made the most effective use of the full range of functionality of the system.

In relation to the site and exterior of the building these were:

- Good balance between modelling of 3D geometry and texture mapping to provide a thoroughly convincing, large scale model of the site, which includes existing buildings of importance to the intervention as well as the wider urban issues such as the adjacent motorway.
- Ability to approach the site, as would a user, by sailing along the canal or, as a wheel chair user, to open gates and wheel along foot-paths to the building entrance.
- Understanding of the urban site by "flying" nearer or further from the adjacent motorway (along which cars are speeding) to check the attenuation of noise pollution.

In relation to the building itself, the contribution of the student's ability to "visit" his design, during the evolution, as would a wheelchair user, was clearly evident in the quality of the design solution and was manifested in a number of subtle but important ways, for example:

- The approach from the canal footpath and the carpark to the front door was carefully considered in terms of slopes and angles.
- The door access and view lines of wheel chair users, on entering the facility (including signage) were completely thought through.
- The elegance of articulation of the building into two zones - wet and dry - was the evident result of:
  - the Boolean operations performed by the student on the volumes;
  - the immediate testing of these in the virtual environment.
- The unparalleled level of detail presented by the student in response to user requirements, was exemplified by :
  - the transparency of the balustrades on the ramps and the sophisticated louvre system on the external glazing - a direct result of the designer's perception, from the user viewpoint - of what is important to someone in a wheelchair. Through every window in the building the student was able to show the appropriate view from the building.
  - concern and commitment to the real experience for a wheelchair user. The sliding door towards the canal could be opened and the user wheeled out into a mesh deck in order to get a first-hand experience of being "on" the water before perhaps, two ramps down, actually getting into a canoe, the mechanism illustrated by an elegant animation.

The client community group were presented with the work of the students, and were impressed by the sensitivity with which the brief was addressed. They are featuring the outcome on their website (http://www.fcccp.org.uk).

Conclusions and future aspirations

As in the earliest days of the introduction of computers into architectural design, the quantum jump is made by students. The work reported here, and which will be shown during the conference is, we believe, the epitome - in the current state of the art - of excellent practice. It makes a breakthrough, we believe, in the evolution of good design ideas, modelled offline but appraised interactively and offers a real prospect for user participation.

There is some way to go, of course, to *design* interactively in a virtual environment. The next step which we envisage is to link to the 3D model the emerging and sophisticated software for the thermal, lighting and acoustics properties of the building. This would allow the user to visualise, dynamically, airflow, temperature gradients, lighting levels and to experience the actual acoustic characteristics of the space as she/he moves through it.

The other exciting development is for representatives of the client/user group to "join" the designer within the virtual environment and to participate directly in the evolution of the design concept. The recent development of a wheel-chair motion platform for immersive virtual environments (4) will allow the future users of buildings like the Sailing Club for the Disabled to navigate themselves, in their own wheelchair, through the virtual building.

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