VIRTUAL REALITY: A SOLUTION TO SEAMLESS TECHNOLOGY INTEGRATION IN THE AEC INDUSTRY?

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INTRODUCTION

In order for VR applications to be successfully implemented in a complex industry such as construction, they must be part of a vertically integrated construction environment. Whether immersive or non-immersive techniques are used in the VR applications, users must be able to visualize design and construction information in 3D, photo-realistic, and interactive images. The user must also be able to interact with external applications at real-time, thus, allowing VR systems not only to be used as presentation tools, but also as a universal interface for all construction applications. Finally, construction professionals must be able to view, alter, test, etc. any function or part of the proposed design and at any stage of the project life cycle through the virtual space. Because of the magnitude and complexity of the construction projects, the traditional way of doing business in the construction industry is to divide the whole project into work packages according to well-established specialization. The work packages are assigned to specialty designers and contractors respectively. Although a system like this brings significant benefit to the industry, it also results in difficulties in communication and extensive collaboration among the participants of the project.

The communication between the segments of the project relies mostly on drawings and specifications. Project participants acquire from these paper-based media information only relevant to their own specialty. Confusions and delays often occur due to the abstract nature of the said media and the process of constant reinterpretation by the project participants. Although computer applications in every specialty benefits the industry very much, most of these applications can only keep information integrity inside their specific areas. The communications between these independent systems are very limited and sometimes frustrating at best.

VTT (1998), the Technical Research Center of Finland, proposed the interesting analogy of the current integration research in construction area shown in Figure 1. The independent computer applications in specific areas like design, construction and project management, which shows the fragmentation of the construction project, was referred to as "Islands of Automation" or "Islands of Information". The contour line is actually the time axle. The current coastline means the frontier of the research and applications at present, while the coastline of 2000 was the goals that the researchers may achieve before next century. With the advances of the computer technology, breakthrough of some key concepts, and the effort of both researchers and industry practitioners, "the water level has dropped (Froese, 1994)", and bridges are built between the islands. This process will eventually lead to " an integrated construction management system. Figure 1 is an imaginative description of the evolving process of integrated computer applications in construction industry.

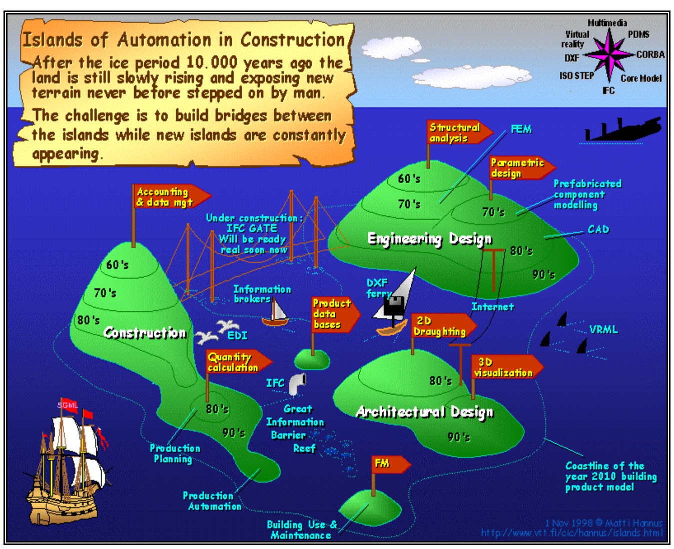

Figure 1. The Islands of Information (From VTT, the Technical Research Center of Finland)

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The great advances in technology integration came in the 1990's. Our whole society was affected by the fast development of computer technology. CAD technology advanced from two-dimensional drawings to 3D visualization and Virtual Reality using VRML became possible. It was recognized that the lack of integration between computer applications in this area could become a major obstacle to the further development. Integration plans were proposed and tested in order to achieve full-fledged production automation under the control of a unified computer system.

The rapid expansion of the Internet has resulted in numerous possibilities and opportunities for the construction industry to make improvements to many aspects of its business operations. Some new areas of applications started emerging, such as product databases, and facility management archives. The current active areas of standardization research include:

- ISO STEP (Standard for the Exchange of Product Model Data): BCCM Core Model, Express, etc.
- CORBA (Common Object Request Broker Architecture) from OMG (Object Management Group)
- IFC (Industry Foundation Classes) by IAI (International Alliance of Interoperability)
- PDMS (Product Data Management)
- Multimedia (Video and Audio), Internet, Virtual Reality, and DXF

These standards form the three important sub-areas of computer integration research:

- **Integration of the Existing Applications:** The major purpose was to establish information standard between the computer applications developed independently. It is like the transportation facilities between Islands in the VTT Illustrations.
- **Investigation of New Specialties:** Some applications are specialized in new specialty areas, such as product databases and facility management.
- **Introduction of New Concepts and Utilities from Computer Science:** The latest development in computer science always means possibilities to the solutions to the current problem in construction industry. This example includes: VRML, Internet, XML, EDI, DXF, etc. They appeared as those objects floating around the island in VTT Illustration.

VIRTUAL REALITY: A SOLUTION TO TECHNOLOGY INTEGRATION?

The basic concept of VR is to model the shape of the objects in three dimensions. The idea of Virtual Reality appeared decades ago, but the inferior ability of the primitive computers at the time hindered data-intensive implementations. The price of equipment was so prohibitive that the application of Virtual Reality had to stay in a virtual status. However, Virtual Reality does have some advantages that put it among the most promising solutions to implement system integration.

The "Ideal" Solution

A VR Integrated Construction System can be expected to:

- enable designers, developers, and contractors to use the VR system and virtually test a proposed project before construction actually begins.
- offer "walk through" view of the project so that problems can be found and design improvements can be made earlier.
- provide free flow of information between CAD systems and other applications work packages by professionals in industry, minimize the misinterpretation between participants of the project, especially between designers and clients.
- facilitate the selection of alternative designs by allowing different plans to be tested in the same virtual world.

In a VR Integrated Construction System, VR becomes the main interface for all application packages and construction information for every specialty throughout the construction (life) cycle of the project.

Two Ways of Interacting with A VR world

There are two approaches to implementing a VR World: immersive and non-immersive. In an immersive approach, the user is surrounded by the virtual world through curved screens and body suits or head mounted devices (HMD). The audio and visual perception of the user will form a virtual world. The non-immersive approach, also known as desktop virtual reality, enables users to interact with the virtual world with conventional devices such as a keyboard, mouse and a monitor. Although this does not give the same level of spatial awareness as the immersive approach, it does provide users with a low cost solution and does not require the use of the HMD. This solution seems to be an attractive compromise for many users who are uncomfortable about spending a long time in a helmet. (CIB, 1999)

VR can be interpreted as a bridge between subject and human perception. These two ways of implementing VR provide solutions from two ends of the bridge. The immersive approach makes human perception its focus, while the non-immersive approach started from the description of the subject. The distinctions between these two styles of VR may eventually diminish with technological advances. But for the current investigation of VR in Construction, the non-immersive approach seems to be more applicable.

Existing Problems of Current VR system

Currently two major functionality of VR in construction is interaction with objects in real-time and walk-through presentation. These features are mainly about visualization and simulation, instead of providing a basic interface between users and the project (subject).

Most of the time VR systems are just supplementary to CAD packages. They can not perform stand alone design let alone be the bases of 2-D drawings and all engineering design. Lots of implementation problems come from the supplementary role of VR systems, and include difficulty in use, requirement of special skills, and expensive to implement. These problems, which mainly come from the lack of integration between application packages, constitute tremendous barriers to the implementation of VR systems in the real world.

What Is Needed To Make It Happen

To make the dream of virtual reality come true, a scheme similar to following needs to be set up:

- VR must become the general interface among the different applications instead of their individual interface.
- 2D and 3D images must become not just a way of presentation, but more importantly they must become interface for interactivity.
- A central core which is a database system (most likely a knowledge based database system) will be the basis of the whole VR system, the application and the interface.
- The VR integrated construction system must be able to reside on a communications network (the Internet or more precisely the WWW).

A serious challenge to the actual deployment of a VR system is whether an Industry Standard is developed or not. Before a complete solution can be provided to the user, the industry must be persuaded to adapt and move to a totally new, standards-based system.

VR APPLICATION PROTOTYPES

Construction Material Specification Integration

The integration of construction drawings, design and material specifications within a VR environment allows the AEC professionals and the owner/procurer of construction services to preview the final product of their effort. This preview allows the participants in the project to more realistically determine the soundness of the design; the appropriateness of the construction techniques and the adequacy of the facility and materials finishes in meeting the owners needs, prior to the execution of the project. Consequently, the expectations of the parties will be more realistic and the risk of costly disputes will be reduced considerably.

Collaborative Virtual Prototyping

Even though VR based tools can be useful in every stage of the construction process (to convince clients, to design the project, to organize and follow the construction site, etc.) important applications are related to the "design phase". Decisions taken during the early design phase are of paramount importance due to their possibly dramatic effects on the final project, timing and costs. Virtual prototyping allows architects, engineers, contractors, and clients to create a design and evaluate it simultaneously for function, cost and aesthetics very early in the design process.

The visual capabilities and the interactive inspection features offered by VR based tools are much more extensive than those offered by standard CAD tools. Furthermore, coupled with distributed technologies such as **STEP** and **CORBA**, VR tools offer cooperative capabilities very useful in the design, by geographically distant teams, of large engineering projects. In that case, the virtual prototype can be considered as the starting point of the design process. After the first stage where the design teams test and validate the virtual prototype, relevant data is extracted from this prototype and is fed into CAD/CAM tools in order to be completed with more technical and detailed data (See Figure 2).

Link with CAD Tools
The reverse process (i.e. extract data from CAD/CAM tools in order to visualize objects in a VR tool) is also possible. Nevertheless, it requires a fair amount of simplification (for evident reasons of performance optimization, detailed data cannot be fed into VR tools as a whole). Furthermore, existing techniques of simplification (polygonal reduction, re-meshing, etc.) still have some limitations particularly for granularity management (a small component that highly effects the virtual scene, e.g. a key hole when simulating lighting effects in a dark room, might be suppressed in an automatic re-meshing procedure).

CAD models aim to represent the geometry of components for their manufacturing or for executing physical simulations (deformations, thermal analysis, etc.) by using methods such as the Finite Elements Method. On the other hand, **VR models** aim to represent visually objects in order to interact with them. Therefore, CAD models can only be used within VR platforms after being processed by optimization procedures such as tessellation. Tessellation can be described as the processing of a 3D model in order to reduce the number of triangles of the model while maintaining an acceptable visual aspect. This procedure has some limitations:

- it could **change the frontiers** on the components of the initial model (which might be a problem when, for instance, two components should keep a perfect fit) ;
- it is rather limited in handling **gaps** and **intersections** in the model.

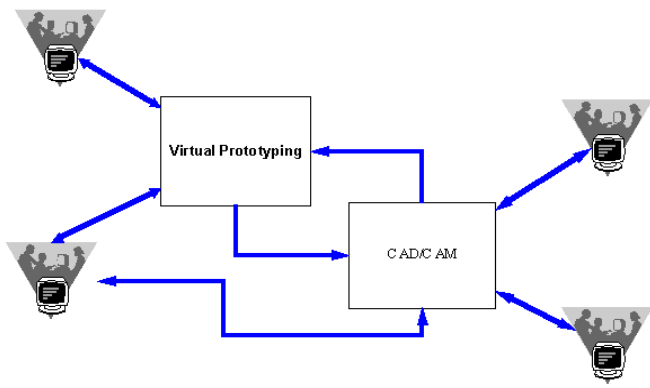

Figure 2. Collaborative Virtual Prototyping (CIB, 1999)

In both cases, manual corrections are usually needed to rectify the simplified model before using it in a VR application. Furthermore importing CAD models within VR tools usually yields a model where some of the facets are missing. This is due to the fact that, in CAD tools, a common way of constructing 3D models is based on **symmetry** (i.e. only half of the model is described and the other half is deduced by using symmetry axis). The "symmetrical copy" of the 3D model would be identical to the original one but would have **inverted normals**. When imported into a VR platform that uses **backface culling** for optimization issues, the "symmetrical copy" of the model will not be visible. A manual action from the user is then needed in order to invert the normals of the model. An interesting optimization tool for CAD/VR coupling is CAD-Real-Time Link from Prosolvia Clarus (http://www.clarus.se).

VR applications for detailed design
During the **detailed design phase**, virtual prototyping tools will allow the design office to refine the design proposed by the architect by adding constraints and modifications induced by the technical calculations (structural, thermal, lighting, etc.):

- **Acoustics**. The results of acoustic calculations can be related to the sound going through a window or a wall or the sound inside a room (e.g. a meeting room). These results are usually 3D sound WAV files associated to the related building components.
- **Lighting**. Different lighting calculation methods can be used. The most effective ones are based on **radiosity** computation and **raytrace** rendering. These methods combined give a high realistic visual feedback on the architectural options taken.
- **Thermal analysis**. At this stage, thermal analysis is done in order to estimate the performance of HVAC systems and/or the comfort in the built environment. This should give a quick feedback on the architectural options taken (orientation, glazed surface, etc.).
- **Documentation/annotations**. During the design, users should be able to access, in line, to relevant documentation and standards about the building components. This can be done by supporting hypertext links

between building components and related URLs. Furthermore, users can attach annotations to a given component or the overall project so they can leave a message or explain a choice to other users (that are not in the same work session).

Construction projects can very easily become complex. Therefore, performance optimization procedures are of paramount importance. Two optimization procedures are particularly efficient in the AEC sector: **scene graph culling** (when the walkthrough takes place in the first floor, there no point in loading the geometry of the other floors) and Levels of Details **LOD** (each of building components, that can be very complex if represented with all there details, have several representations that will be displayed depending on the Level Of Detail required based on the distant of the component from the camera).

These methods, combined with more generic optimization methods (such as **visibility culling** and **backface culling**) should allow complete scalability of the system regardless of the complexity of the construction project.

The Integrated Construction Environment (ICE)

In order for VR applications to be successfully implemented in a complex industry such as construction, they must be part of an Integrated Construction Environment (ICE), Figure 3. In such environment, construction applications packages are integrated through a central intelligent core whereby project information is controlled, maintained, and manipulated. The user interface for this environment should have the ability to convey project information in a human acceptable level i.e. elements, spaces, resources, etc. At this end, VR can play a major role in the development of a human computer interface for the ICE. Whether immersive or non-immersive techniques are used, users can visualize design and construction information in 3D, photo-realistic, and interactive images. The latter facility allows users to interact with external applications at real-time, thus, allowing VR systems not only to be used as presentation tools but as a universal interface for all construction applications. Construction professionals can view, alter, test, etc. any function or part of the proposed design and at any stage of the project life cycle through the virtual space.

In the short term, VR (non-immersive) can be used, as a modeling tool, to complement current design tools such as CAD systems. This implies that VR can be considered as an application package within the ICE, which aims at providing flexible, realistic, and interactive presentations. Once VR models are generated in virtual space, users can navigate through the product, at its current stage of development, and interact with any design elements or spaces to access further information or run external simulation programs. Users' movements and queries are monitored and controlled by the intelligent central core of the ICE.

VR, as a universal interface, can be enhanced by video conferencing. Communications between different members of the design team or between design team, builder and owners can be significantly improved by using a combination of VR and video conferencing techniques. If VR models are generated automatically from the traditional design tools at the local design office, such models can be transmitted to the client's remote site. Clients can navigate through the product and/or request alterations to the design or part of the design by simply pointing or moving the concerned elements. Alternative solutions can then be suggested by the designers and represented to the clients for final approval. The same scenario can be applied to improve communications between various members of the design team.

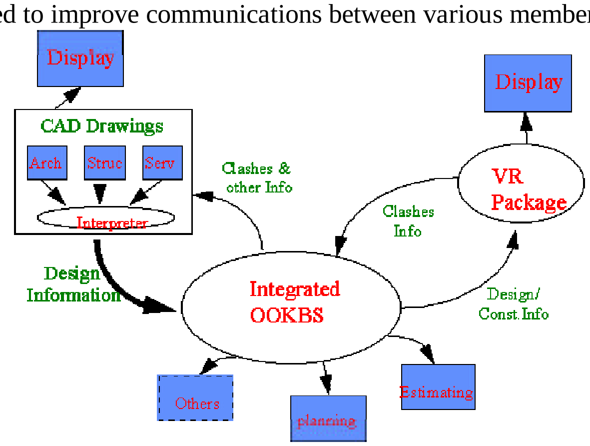

Figure 3. Conceptual presentation of the ICE

A prototype of such product has already been developed by the AIC (Automation and Integration in Construction) research group at the TIME Research Institute, University of Salford. At its current stage of development, the prototype "SPACE" (Simultaneous Prototyping for An integrated Construction Environment) integrates six construction applications with the central data models. The applications are: design, specifications, estimating, construction planning, site layout planning, and virtual reality (Alshawi, 1998).

In the long term, VR (fully immersive) will offer the average user the potential to enhance the final presentation by combining 3D images, head-mounted displays, sounds, and self-movements. The ability to support the illusion of the individual's movement through the virtual space will make the implementation of VR much more acceptable to humans. Users will be able to feel/see their movements in space, thus, improving the performance and well-being of the ultimate human user. Users' movements and requests, in virtual space, will be monitored and controlled by an intelligent and integrated knowledge based system and other external construction applications where all communications with external applications' are carried out in virtual space in either a textual or graphical format.

The flexibility offered by virtual environments to visualize and interact with the virtual world, provided that these technologies are available at a reasonable cost, will enable designers, clients, and contractors to use VR to rapidly construct and test their prototypes before constructing the actual project. But this only happens if the strengths of the technology are emphasized and the hype is significantly played down. VR should be treated not as a technology in its own right, but in terms of a suite of technologies which, if carefully implemented, are capable of matching the capabilities of humans to the requirements of the application or task he or she is required to work with.

The potential of VR can only be realized if it is integrated with AEC application packages. An integrated construction environment should be developed where all construction applications are integrated through a central intelligent core. VR can play a major role in the development of a human computer interface for such an environment. Whether immersive or non-immersive techniques are used, users can visualize design and construction information in 3D, photo-realistic, and interactive images. Moreover, VR displays and interactive devices should only be selected on the basis of a) human factors issues i.e. what is expected of the performance and well-being of the ultimate human user, and b) customer requirements

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