

Real-Time Interactive Simulation: Framework to Facilitate Application during Design Stage

Komal Patel[1], M.S. and Khalid Siddiqi[2], PhD
Kennesaw State University, Marietta, Georgia

Construction projects start with some uncertainty and assumptions to formulate the final design within estimated budget and time. 2D- 3D model generation and walkthrough are traditional methods to demonstrate design to owners but now, construction industry is merging with real-time simulation industry. The demonstration technique is called Real-Time Interactive Simulation (RTIS) where a user can virtually enter into a building to connect with future operations. However, the AEC industry is not very familiar with this new technology because criteria for implementing the technology are blurry. The objective of this paper was to develop criteria for application of RTIS during design stage. The study was carried out in two parts. Criteria for technology implementation were identified by studying published papers and interviewing RTIS users namely architects, 3D artists, and programmers. For validation of each criterion, they were compared with real-time interactive projects. Study results would guide architects in implementation of RTIS and that can also be used as a marketing tool by architects.

Keywords: Design Stage, Design Demonstration Technology, Development of Real-Time Simulation, User Interaction, Virtual Reality

Introduction

Traditionally, building architects have been using 2D and 3D models to present their design concepts to owner. With the current technological advancements and to improve project visualization, architects are now focusing on using gaming software for Real-Time Interactive Simulation (RTIS) (Whyte, 2003). The visualization technique of 3D world is impressive and use of such techniques to visualize and review a construction project design is a good alternative to the existing conventional 3D models. Tahriri et al. (2015) suggested that design visualization technique allows the user to coexist in the same virtual environment as designed model. It also allows for design interaction in terms model manipulation and functional operations.

Complementary are the advancements in a gaming industry that have been developing where researchers have been exploring 3D computer graphics making it more applicable to the construction industry. The question of finding ways of applicability to the construction field has been the subject of numerous papers and projects. It was also found that the models generated with RTIS could be used in application of Virtual Reality (VR). The concept employed in application of VR is the use of RTIS model in VR display devices. Researches on VR suggested the benefits, challenges and scope of the research subject.

The objective of this research was to develop criteria for application of RTIS during design stage. Use of RTIS in the AEC industry is a new concept. Therefore criteria could be developed to enhance the use of RTIS technology during design stage and that was the hypothesis of this paper. If framework settles up in the form of criteria, then it would help the architect who wants to implement RTIS for better visualization of conceptual design. This research attempted to gain knowledge in the field of construction industry using real-time interactive simulation.

In this paper, design stage is defined as the stage where structural, architectural and MEP drawings, are finalized and updated with specifications. So it is the point of freedom in any project to make changes (Kassem, 2012). So RTIS is a good technique to show project with user interaction with numerous changes. However, RTIS is different from BIM applications because RTIS focuses on visualization but, not on conflict management.

Background

Real-time models were used in the past to illustrate construction and construction operations (Huang and Halpin, 1994). RTIS/ Virtual reality is the type of computer interacting technique where users can virtually interact with real-time simulation of activity or environment (Lohse et al., 2014). Real-time interactive simulation is the technique that gives better view with user interaction technique in which conventional methods of 2D and 3D modeling is ineffective and unfeasible (Kamat and Martinez, 2001). Computer simulation is the process of designing models by using logic and principles of mathematics and experimenting with computer models.

Yongzhe et al. (2013) researched fire and smoke simulation in high-rise buildings. Real-time interactive simulation model in Unity 3D- the gaming software, helped them to generate stake effective fire model and smoke boundaries. The Europe based company developed a model in real-time and that was used to improve management and business practices in the AEC industry. Graphical forms of a building proved the use of the technology is not only limited to visualization but also extended to scheduling (Abdelhameed 2012).

In another study, real-time interactive market was surveyed for a residential house by interviewing buyers of property. Positive selling results were noticed by allowing buyers to interact with a building interior and appliances (Mahdjoubi et al., 2014). This result clearly reveals that along with bringing clear visualization, RTIS can also be used as a marketing tool. In addition to this, research on virtual reality application in construction operations was carried out to train drivers for equipment operations. Through real-time interactive simulation, drivers experienced virtual accidents and that helped to improve safety standards (Yuen et al., 2010).

After analyzing the literature, it was determined that rather than generating and analyzing one project, study on different case studies from the AEC industry would be the best approach to set up the framework of RTIS.

Research Methodology

This research was approached in two parts. Literature review and analysis helped to build familiarity with the topic and to prepare questionnaire. Based on discussion with the technology users and real-time projects, 6 major criteria- time, software, skill, model development techniques, devices and cost were established. Discussion was in the form of interviews, face-to-face and online, with the technology users. The study focused on a limited number of users because RTIS is a new technology. Surveyed companies were the ones, who just started implementing RTIS in their firms. That gave guidance to understand challenges they faced in implementation and that helped to set up the criteria. As mentioned earlier, this technology is more useful for architects during design stage to visualize the project design but the contractors who are engaged in design-build projects also can utilize it to show the design ideas. Further discussed projects give the idea of RTIS implementation with both perspectives.

Data collection and analysis

Figure 1 shows the general process of RTIS implementation. The best way for development of this technology from 2D drawings to RTIS implementation is shown in three-step process workflow. After exporting the 2D model to 3D modeling software, the next step is to generate a 3D model with texturing. The complete model should be exported as a Filmbox (FBX) file to the real-time software where a programmer can simulate it to create a scene. These scenes are the same as AutoCAD Revit walkthrough but users can interact with the model due to its user interactive coding simulation.

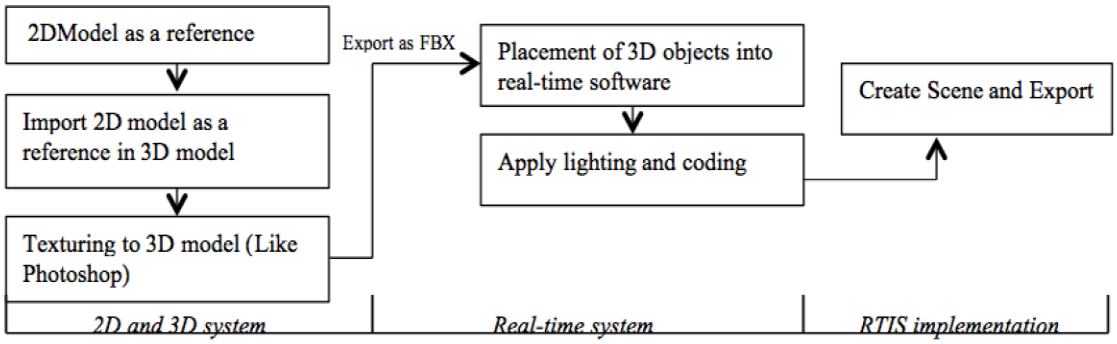

Figure1: Workflow of 3D modeling to Real-time model *(Shiratuddin, M. F., & Thabet, W. (2011))*

Table 1 presents the summary of several projects where the RTIS model was successfully used. Although survey results are not only based on projects mentioned below, research papers and other projects from companies with a small-simulated model were also studied. The table shows the cost range of various projects listed where 1 is for the project cost of less than ten thousand dollars and 4 is for more than 1 million dollars. The Sea-Beach and Metro Transit System projects were big scale projects where this technology was used to generate a complete model with all expertise. Project complexity was high in the Metro Transit System project. The client design was proposing the parking garage and the subway station separately but the architect was offering the design where both the design segments were connected together. To visualize this high level of design complexity, different design angles were required. In this case, the traditional 3D animation approach was not competent due to its extensive rendering period. The team of architects created single real time scene to visualize multiple angles and that technology is called RTIS. Where as for the St.Luke's Hospital project, general contractor used this technology for the resuscitation and exam rooms only. The unique technology allowed the user to get an accurate feel for the size and the orientation of the room and equipment. The suggestions from the end users helped the general contractor to modify the design changes and its implementation with the end user perspectives. However, this study was focused more on projects where RTIS was used as a new concept for visualization so that difficulties faced by users could be identified. Data was analyzed from six key perspectives. The problems faced by the company in generating real-time interactive model were studied and the proposed RTIS implementation model along with the list of criteria was developed.

Table 1

List of several projects with Real-time interactive simulation

Project Name	Team	Duration to generate model	Gaming software	Modeling Software	Cost Range
Sprint Center, Kansas City, MO	1 Programmer + 1 Artist	1 Month	Unity 3D	Revit	3
Commerce bank, St. Louis, MO	1 Programmer + 1 Artist	3 Week	Unity 3D	Revit	2
KKG (1 Bed apartment), Kansas City, MO	1 Programmer + 1 Artist	1 Week	Unity 3D	Revit	1
Military simulation Tower	2 Programmer+ 3 Artists	5 Month	Unity 3D	Revit	2
Subway Station, DC	1 Programmer + 1 Artist	1 Month	Unreal	3Ds Max	4
Highway extension	1 Programmer + 1 Artist	1 Month	Unity 3D	Revit	2
Department of Transportation, CA	2 Programmer+ 2 Artists	-	Unity 3D	Revit	3
Sea-Beach Project, Newyork City, NY	1 Programmer + 1 Artist	4 Months	Unreal	3Ds Max	4
Metro Transit System, Seattle, WA	1 Programmer + 1 Artist	6 Months	Unreal	3Ds Max	4
St.Luke's Hospital, Kansas city, MO	1 Programmer + 1 Artist	1 Week	Vizard	3Ds Max	3

Project Cost Range $: **1**<10,000; 10,000<**2**<100,000; 100,000<**3**<1,000,000; 1,000,000<**4**

Simulation Software

From the study of literature and the projects, it was found that the majority of companies were using Unity and Unreal as gaming software. But it is also found out that private virtual reality developers are using their own products that include Vizard. Among Unity and Unreal, the popularity of Unity is more due to its user-friendliness. From the discussions, it was found that Unreal game engine is a good competitor of Unity in simulation industry. Sea-Beach and Metro Transit System projects were the one where company successfully used the Unreal game engine. The following benefits of Unreal over Unity were found: better in quality, virtually powerful rendering engine, animation cut-scenes, powerful artificial intelligence (only applicable to objects, which are not in control of simulator like crowd simulation), landscape editor for big scale projects, powerful material editor for final look of the model.

3D Model Generation Software

In the market, there are plenty of modeling software available like, Revit, 3Ds Max, Maya, sketch up, MicroStation. Among all software, AutoCAD Revit is more popular but considerable differences exist between RTIS software and AutoCAD Revit. According to Li and Zhu, (2009) "The real-time model is time critical and more vivid, while CAD model is more precise but less realistic" (Li and Zhu, 2009, p. 352), and it is for more of architectural applications. Because of this, AutoCAD Revit model takes more time to simulate in the gaming software.

From discussions with companies, it was found that using 3Ds Max instead of Revit makes simulation easier for programmer. By using 3Ds Max, the company saved 2 to 3 and 4 to 5 weeks on Sea-Beach and Metro Transit System projects respectively. They also discussed several drawbacks of AutoDesk Revit such as higher level of 3D model detailing, multiple materials on single object made file sizes heavy to simulate in simulation software. They also suggested that 3Ds Max uses proper guidelines of simulation software including model resolution.

Skills

Success in any project is influenced by specifying software requirements and its analysis (Saiedian et al., 2005). Software requirements also suggest skills for its operators. In case of real-time interactive simulation, programmers and artists work together as a team and both of them need to have specific skills as stated below.

1. Programmer: Programmers with knowledge of basic math and physics, vector math, coding language and on top of that, detail knowledge of gaming software make them more efficient in this field. But it is not limited to that only; basic idea of AEC industry and its terminology are another requisites. It would make it easier to coordinate with artists and architects with whom they work.

2. Artist: In construction, artist is defined by the person who gives an artistic look to the building in the form of 3D model. A detail oriented person with in-depth knowledge of scaling, mapping, texturing and basic knowledge of gaming software would make it flawless in the application of real-time interactive simulation.

In the Sea-Beach project 1 programmer and 1 artist worked together as a team. Within 2 month of time period, it was difficult to generate model in real-time but correct blend of basic skills, use of software and communication network helped them to finish. The company organized the manpower for its next project of Metro Transit System from successful implementation of RTIS in Sea-Beach project. Overall, it was concluded that knowledge of one's own field and basic knowledge of other fields would bring ease in team coordination.

Model Development

In this section, ways are discussed to make the implementation of real-time interactive simulation easy to work throughout. One way is to have good library from where programmer can store data in the form of construction elements and their simulation. For instance, when a company started their first project of Sprint Center, it took a month to generate all the elements of the project. But pre-built stored elements helped programmer to finish the next project of KKG project in a week. In the Sea-Beach project, pre-developed library helped artists to modify and use it for transportation project, which includes cars, crowd, trees, and water flow creation whereas, programmer used traffic simulation, crowd simulation and interactive camera views from loaded library. Further to this, artists and programmers used the same library for their next project of Metro Transit System, which was falling under the same category of transportation.

Demonstration Device

High configuration computers are required for this technology especially for simulation software. Research by Yongzhe et al. (2013) and Wu et al. (2011) proved this subject by their projects. Table 2 shows basic technical computer configurations for implementing RTIS includes simulation and modeling. The criteria specified below help the user to identify the need of the resource from procuring perception includes processer speed, operating system, minimum random access memory and processor unit requirements.

Table 2

Computer Configurations needed in implementation of real-time interactive simulation

Criteria	For simulation	For modeling
Processor	i7	i5
Operating system	Microsoft 7, Windows8, Mac	Microsoft 7, Windows8
Random Access Memory RAM	16GB	4 GB (8GB recommended)
Graphic Processor Unit (GPU)	Higher end NVidia (Not more than 1 year old)	Not less than 2 years
Central Processing Unit (CPU)	32-bit Intel or AMD multi-core processor (Recommended 64-bit)	64-bit Intel or AMD multi-core processor

Cost

Cost includes cost of manpower and resources. Survey by PayScale in 2015 of average hourly pay of 3DsMax artists and programmer was $20 and $30 respectively. The data for above-mentioned projects is mentioned in table 3. In the first three projects of table 1, company discussed about their cost data. For Sea-Bach project, the scope of work was covering the renovation of a subway station. For that the architect spent fewer hours with less design complications. Whereas design and construction of Metro Transit project was part of the project scope but that with more design complexity as mentioned earlier in table 1 description. The company spent more resources to finish the project in 6 months as discussed in table 4. So as per the discussion it was found that, the price per square foot might vary with a complexity of the work and a use of the software.

Table 3

Cost distributions for Sprint, Commerce bank and KKG in implementation of RTIS

Cost of Manpower		Cost of resources	
Programmer ($/ hour)	**Artist ($/ hour)**	**Unity ($/year)**	**Autodesk Revit (Unlimited Use)**
18-20	15-18	4000	5775

In the case of Sea-Beach and Metro Transit System projects, which were large projects compared to other projects in the list. Detailed cost distribution is in table 4 and 5 below.

Table 4

Cost distributions for the Sea-Beach project

Working hours			Cost of manpower		Cost of Resource	Cost of Project
Engineering Team	**Real-time interactive Team**	**Proposal team**	**Programmer ($/Hour)**	**Artists ($/Hour)**		
1900	770	1100	37.5	25	3000	25 Million

Table 5

Cost distributions for the Metro Transit System project

Working hours			Cost of manpower		Cost of Resource	Cost of Project
Engineering Team	Real-time interactive Team	Proposal team	Programmer ($/Hour)	Artists ($/Hour)		
4800	1920	640	37.5	25	3000	1.2 Billion

It is a fact that this technology is costly and requires specific skills to accomplish needs. But it is worth it for companies who are in search of implementation of the new technology especially for visualization. For the above mentioned projects, survey

Results and Inferences

The paper has met its intended purpose of developing the criteria for RTIS by identifying and reviewing the relevant multiple case studies and projects. Each criterion's interpretation was analyzed. Results in terms of need and correlation of each criterion among others with the purpose of understanding system implementation as a whole, was deemed most beneficial to the architects and GC for design build projects. The majority of the projects studied followed different system for implementation. However, the best system of RTIS implementation is suggested in the graph shown in Figure 2. It is approached in five stages, starting from defining criteria to RTIS use at the design demonstration stage. It is the responsibility of each team member to coordinate with others to accomplish each stage. This paper should be referred to by architects at first stage to determine criteria for design development and model simulation.

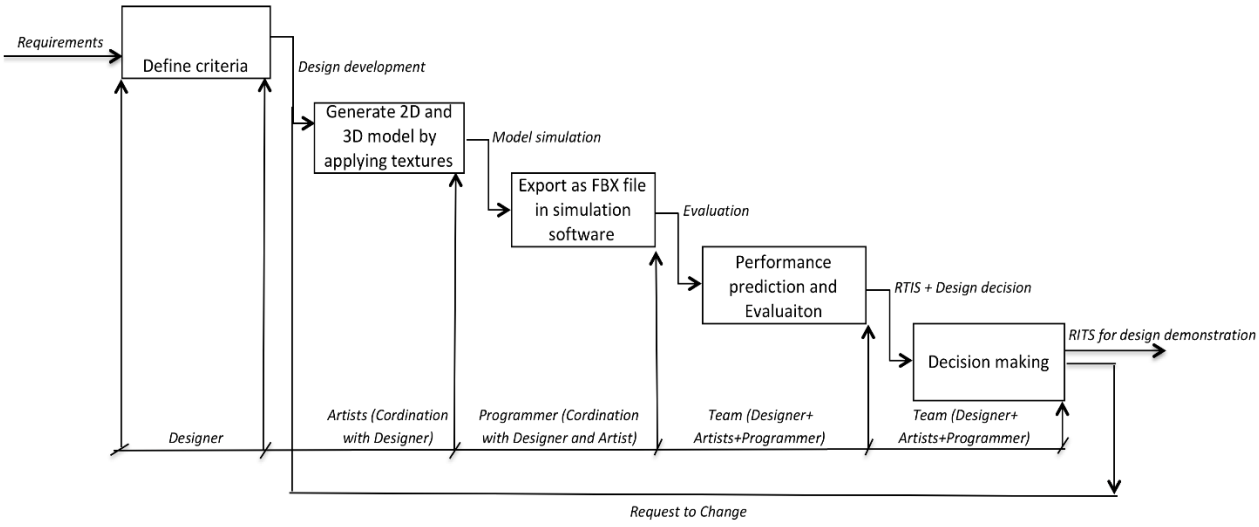

Figure 2: Proposed RTIS implementation model during design stage (Zhang, X. M. (2006))

Table 6 illustrates the list of criteria and need of each criterion. This study effort in generating implementation criteria made the application of RTIS more viable for the architects. It was also found that these criteria could be also useful for military and construction operation simulations.

Table 6

List of Criteria for implementation of real-time interactive simulation

Criteria	Requirement
Time	Time, with its associated costs, was extremely important for each participant in the construction. So for RTIS users it was necessary to know how this system works and what the needs of implementation are. It is the fact that any initial practice takes time but selection of proper resources at preliminary stage may help to reduce time with respect to cost.
Software	These are the best software, which would help in RTIS implementation. Model generation: 3Ds Max, Revit, Texturing: Photoshop Simulation software: Unity, Unreal It is recommended to use Unity for small projects where visualization is more important than quality whereas, Unreal helps to bring quality with better visualization. However, combination of 3Ds Max with any of the simulation software is to be found more feasible and accurate.
Skills	Purpose of listing the skill was to identify specific type of RTIS team members needed by architects. In addition to required skills, it was necessary to have coordination among each team member as explained in figure2 above.
Model Development techniques	It is necessary to generate some of the database in advance to save time and avoid repetitive work. Simulation library and pre-built animated objects can help programmers and artists respectively.
Devices	It is true that simulation software demanded the latest high-configuration computers not later than 2 years. So architects are required investing specific type of devices to run the system.
Cost	It is true that the implementation is not cost efficient but cost effective advancement by the simulation software companies, detailed guidelines for implementation and positive RTIS implementation results would attract more architects. More detailed implementation of RTIS by companies would help to define per square foot cost of this technology.

Conclusion

Prior studies on RTIS have focused more on examining one project by concluding technical details of software. This study analyzed the requirements of RTIS implementation in AEC industry by establishing the framework. The framework was entirely based on literature and real-time projects.

It was found that architects were interested in implementing RTIS but lack of information about requirements and implementation techniques made it unsuccessful. The criterions developed in this study are expected to facilitate users for adopting RTIS. Although the period when this research was carried out, the concept of RTIS in AEC industry was new, these criteria could be improved after studying multiple complicated projects.

Along with implementation criteria, RTIS implementation model is also proposed. It shows different stages of RTIS enactment and roles of each team member. This model would guide architects to allocate resources and to form a skilled team.

During this research it is found that general contractors also can use RTIS for design-build (DB) projects. The term DB itself presents that general contractor engages into the project with single responsibility of design and build. In this case, RTIS helps to present the design to owner. Apart from this, architects are using RTIS models as a marketing tool and that proved to be their successful design presentation. Real-time interactive simulation model can also be used for virtual reality devices to make it more user interactive. So it could become a good study by showing procedure of applicability of RTIS model for virtual reality devices. This paper can be further extended by focusing

more on simulation software and suggesting the best possible ways to connect simulation software to modeling software.

Acknowledgments

The author would like to thank all companies and individuals who responded to the surveys. Of the special mention are HNTB, Arch Virtual Developers, JEDunn Construction, WorldViz, LLC and Virtutecture LLC, for their feedback and valuable time for discussion of their projects. I would also like to thank co-author Dr.Khalid Siddiqi for his assistance and encouragement.

References

Abdelhameed, W. A. (2012). Virtual Reality Applications in Project Management Scheduling. Computer-Aided Design & Applications (Computer-Aided Design & Applications), 9(1), 71-78. doi:10.3722/cadaps.2012.71-78

Huang, R., and Halpin, D. W. (1994). ''Visual construction operation simulation: the DISCO approach.'' J. Microcomp. in Civ. Engrg., 9(6), 175 – 184.
Kamat, V. R., & Martinez, J. C. (2001). VISUALIZING SIMULATED CONSTRUCTION OPERATIONS IN 3D. Journal Of Computing In Civil Engineering, 15(4), 329.

Kassem, M., Dawood, N., & Mitchell, D. (2012). A decision support system for the selection of curtain wall systems at the design development stage. Construction Management & Economics, 30(12), 1039-1053. doi:10.1080/01446193.2012.725940

Li, X., & Zhu, H. (2009). Modeling and Visualization of Underground Structures. Journal Of Computing In Civil Engineering, 23(6), 348-354. doi:10.1061/(ASCE)0887-3801(2009)23:6(348)

Lohse, K. R., Hilderman, C. E., Cheung, K. L., Tatla, S., & Van der Loos, H. M. (2014). Virtual Reality Therapy for Adults Post-Stroke: A Systematic Review and Meta-Analysis Exploring Virtual Environments and Commercial Games in Therapy. Plos ONE, 9(3), 1-13. doi:10.1371/journal.pone.0093318

Mahdjoubi, L., Hao Koh, J., & Moobela, C. (2014). Effects of Interactive Real-Time Simulations and Humanoid Avatars on Consumers' Responses in Online House Products Marketing. Computer-Aided Civil & Infrastructure Engineering, 29(1), 31-46. doi:10.1111/j.1467-8667.2012.00775.x

Saiedian, H., Kumarakulasingam, P., & Anan, M. (2005). Scenario-based requirements analysis techniques for real-time software systems: a comparative evaluation. Requirements Engineering, 10(1), 22. doi:10.1007/s00766-004-0192-6

Shiratuddin, M. F., & Thabet, W. (2011). Utilizing a 3D game engine to develop a virtual design review system. Journal of Information Technology in Construction–ITcon, 16, 39-68.

Tahriri, F., Mousavi, M., Yap, H. J., Siti Zawiah, M. D., & Taha, Z. (2015). OPTIMIZING THE ROBOT ARM MOVEMENT TIME USING VIRTUAL REALITY ROBOTIC TEACHING SYSTEM. International Journal Of Simulation Modelling (IJSIMM), 14(1), 28-38. doi:10.2507/IJSIMM14(1)3.273

Whyte, J. (2003). Innovation and users: virtual reality in the construction sector. Construction Management & Economics, 21(6), 565-572. doi:10.1080/0144619032000113690

Wu, D. L., Zhu, H. M., Zhen, X. J., & Fan, X. M. (2011). Tools and equipment modelling for interactive assembling operating in a virtual environment. International Journal Of Production Research, 49(7), 1851-1876. doi:10.1080/00207541003604828

Yongzhe, X., Eunju, K., Kyunjoo, L., Jaesug, K., & Byungsoo, L. (2013). FDS Simulation High Rise Building Model for Unity 3D Game Engine. International Journal Of Smart Home, (5), 263.

Yuen, K. K., Choi, S. H., & Yang, X. B. (2010). A Full-immersive CAVE-based VR Simulation System of Forklift Truck Operations for Safety Training. Computer-Aided Design & Applications (Computer-Aided Design & Applications), 7(2), 235-245. doi:10.3722/cadaps.2010.235-245

Zhang, X. M. (2006). HyCon: virtual prototyping in hybrid concrete construction frame design. Construction Innovation (Sage Publications, Ltd.), 6(1), 47-60.