Visualization and Simulation Approaches In Construction

Mohammad Jamal Uddin

Department of Architecture, Building Realization and Robotics Lab, Technical University Munich, Germany

* Corresponding author (jamul.uddin@tum.de)

Purpose As robotics and automation technologies are integrated in building construction processes, it is also necessary to visualize and simulate the construction work with the help of augmented reality. Model simulation and visualization can help project engineers to estimate construction schedule, workforce necessity, proper utilization of resources and to meet the client's demand precisely before the beginning of real construction work. Engineers can also monitor detailed construction work during realization and simulate on-site activities with the table-work. Method This paper is aimed to analyse some projects, identify the common project failures and common reasons behind the failures of those projects. Analysis of research papers for some proposed visualization systems for pre-project estimation was done throughout the paper. Results & Discussion In addition the author proposes visualization and project monitoring approaches encouraged by indoor navigation systems. Workflow with augmented reality during construction lifecycle was discussed in this paper. However, author aims for demonstrating the achievable degree of efficiency by augmented reality before and during construction process. Nevertheless a comparative study was done for evidencing the advantages of visualization approach.

Keywords: visualization; construction-visualization; construction-simulation.

INTRODUCTION

The conventional building construction process is replaced by more efficient industrialized form and the increasing globalization demands for short time consuming projects with quick return of investments but containing high degree of accuracy. Due to the continuous degradation of quality, productivity, skilled manpower and working environment, to compete with other products in the market -- the investors in construction sector looked for revolutionary change. The inclusion of automation and robotics aimed to accomplish the demand and can be said that could attain the goal into a satisfactory level.

In beginning of the research for automated and robotized construction process, the majority of the researches focused on hardware and software development which are obvious in areas such as concreting, steelwork lifting and positioning, finishing works and planning software prior to the real construction works. Little attention has been given to investigating the factors that affect the infiltration of these technologies into the construction work site and processes. Previously, researchers predicted that construction sites will gradually become “intelligent and integrated” as materials, components, tools, equipment and people will become components of a fully sensed and monitored environment. Automations of construction processes is considered to replace manual hazardous labour and labour-intensive tasks such as welding and high-steel work by wirelessly networked with sensors and communications technology based construction sites. This automated construction sites will ensure highly efficient, risk free, less time consuming tasks performed by the construction workers who are well trained with the work they are performing.

Upon the findings of different real construction works, researchers sorted out some common project failures and the reasons behind those failures. Visualization of projects before going to the action is supposed to be an important solution to avoid the project failures. Visualization approach can also help to run the construction work on schedule, because detailed works are closely monitored by the supervisor. Simulation technologies can enable planning and analyzing construction operations performed in advance anticipating problems of efficiencies that would occur in the implementation phase. Therefore, simulation systems are used to design optimal resources to supply in a construction operation and analyze an ongoing operation to be evaluated and refined.

Navigation technologies also can serve a great purpose to ensure the best possible outcome in a construction work. Proper utilization of usual navigation and indoor navigational approach can come out in handy to avoid project failures.
**SOME BIG PROJECTS ANALYSIS AND THEIR FAILURES**

**Sydney Opera House**

The Sydney Opera House is considered as one of the canonical examples of project failures with major budget overruns accompanying significant delays. The reported failures are:

- The judges put in place a 'stage gate' process to evaluate entries, but then they were disappointed. The beautiful 'sail' design, the one which is ultimately selected actually could not meet the selection criteria but anyway the judges liked and selected the design throwing all the selection process aside.
- At the beginning of the real construction work, actually there was no clear concept of how it is possible to construct the roof. It’s not that all the estimates were wrong, it's that there was nothing to base the estimates on in the first place. The roof was designed and built many times which caused much of the delay and cost overrun. After continuous repeating of the same task, engineers comes out with the solution to construct the roof out of interlocking tiles.
- Though Opera house is one of the greatest architectural masterpieces from last century, but it failed on cost and field estimation.

**Scottish Parliament**

Regardless of winning many national and international rewards for its architectural excellency, the Scottish Parliament is also criticized by experts for certain reasons:

- It overran initial costs by a factor of ten and was delayed by 3 years. The design was not finalized before construction work took place like the Sydney Opera House. The budget of the whole building was not according to credible cost estimation process. Among five selected finalists, none of them adhered either to the user brief, an area of 20,740 metres squared, or the budget of £50 million.
- The architects changed the design few times which caused them to add 4,000 square meters more with the initial design. The additional land caused to increase the land consumption about 14% to the original design area.
- There was complexity to balance between the sponsors’ desire to have the parliament ready as soon as possible and the architects’ desire for a “gestation period” to really flesh out his design together with a need to be engaged in all decision making.

**Toshka Project**

The New Valley Project or Toshka Project is one of the biggest projects in middle east ideated by the Egyptian government in 1997. This project consists of building a system of canals to guide water from Lake Nasser to irrigate the sandy wastes of the Western Desert of Egypt, which is part of the Sahara Desert. The objective of this project is to facilitate the local communities who live on agriculture and industries by developing a new valley in addition to the existing Nile Valley. It is viewed as a highly ambitious project by the experts which was meant to help Egypt deal with its rapidly growing population. But so far the advancements achieved and prospects of the project indicates that it was ill-conceived and it looks set to be a grandiose failure. The failures so far observed are:

- Toshka’s total budget has been estimated from as low as US$83 million (according to numbers from the Egyptian government) to a whopping US$87 billion (according to the US State Department). less than 25 percent of the original budget has been spent already, but the results are piecemeal. The only objective met so far, is the diversion of water from Lake Nasser into what little of the Sheikh Zayed Canal was built. The canal is currently 60 kilometers short of the first of the oases through which it was supposed to run, Baris.
- Toshka’s original objectives were set in two phases: in the first one, the Sheikh Zayed Canal would be completed and 550,000 feddans (an Egyptian unit of area equal to 1.038 acres) would be reclaimed. At the end of the second phase in 2017, a total of two million feddans would have been recovered from the Western Desert. On the contrary, In 2005, the government announced that it was abandoning the second phase entirely and that the deadline for the project’s completion was extended to 2022.

From the analytical study of the projects stated above, when anyone start looking at major delays and extreme cost overruns, these culprits emerge:

1. **The Teleport**

   No one disputes that teleporting is a phenominal idea. Yet, no one has any idea how to implement it. A lot of failed projects are like this. These sorts of projects often arise when the stakeholders get more excited with the ideas than considering the budgets and feasibility. Resource based forecasting isn’t possible because there’s no precedent and the feasibility of the idea is only understood very late in the execution phase of the project.

2. **The Winner’s Curse**

   A bidding process would seem like a sensible way to find the lowest cost provider for a project. In practice it doesn’t always work that way and the winner’s curse means you may often end up selecting not the cheapest vendor, but the one with the least reliable estimates. They appear
cheapest, but only because they haven’t effectively gauged what it will actually cost to do the work. Once they are selected as a vendor, they then have leverage to increase costs and things unravel from there.

3. The Camel
Just as a camel is a horse designed by committee, so camel projects lack one person in command, and typically have large groups of people calling the shots. All projects have large numbers of requirements, but because of the large number of stakeholders these requirements cannot be scoped down to a level that will enable the project to be completed within expected time and budget.

COMMON REASONS FOR PROJECT FAILURES
In general, all the project failures occur due to the following reasons.

1. Failing to plan is planning to fail.
24% of projects fail outright, but given a new project people typically like to get stuck in believing they’ll be successful. Perhaps they will but stats suggest that you should spend 20% of the duration of the project planning it. Seems counter-intuitive, but many mistakes are avoidable by thinking things through in advance. For a 3 month project, that means the necessary planning time is 12 days, that might feel like an unwelcome delay, but the impact on project effectiveness will be dramatic. Poor planning by not taking into account risks involved in projects, sequential transmittal of drawings, expected arrival of materials, poor controlling of delayed activities and cost overrun activities, poor project review and poor team development or no development are also some important reasons behind project failure.

2. Pre-mortems
People love to be optimistic, a pre-mortem does the opposite. A post-mortem is looking at things after they have happened for success and failure. A pre-mortem considers that the project has failed (an assumption) and invites participants to look at why that’s the case. The assumption of failure frees people up to poke holes in the plan and think about a better outcome.

3. Communication
Most project failures are due to lack of communication, people don’t communicate. The project manager must have a strong base of communication to ensure the project’s success. Poor management can shoot up the cost be it material or labour and the contractor has to bear the additional charges. Also reviewing the project management time to time and reallocation of funds and changing the critical path can be resulted into major failures.

PROJECT VISUALIZATION AND SIMULATION
Construction projects have many unique configurations and the unique nature of projects is very crucial to make planning decisions. Visualization and simulation systems allow the planners to overview the existing model and at the same time to make a quick glance into the real construction processes. When models accurately represent the construction operations, the model complexity increases significantly. Consequently, the effort required to create and maintain these models increases. Planners continuously add features and necessary equipment to overcome the constraints they experience during the simulation of the model. The planners can experience all kinds of constraints in their simulation system which they are supposed to experience when the real construction work goes on.

Because of the complexities found during the simulation and visualization process, construction managers can develop plans that may simplify the effect of the project’s geometric configuration on the construction process. Instead of accurate and in depth process analysis early in the project, the common practice is keeping the process plan at a macro level and creating a detailed plan for shorter intervals as the project proceeds. This prevents earlier consideration of problems on site and evaluation of alternatives.

Can the modeling effort be simplified with reasonable assumptions while maintaining or increasing the power of the resulting models? Intuitively the modeling of operations can be simplified by basing models on the spatial configuration and making effective use of geometry. By managing spatial effects effectively, allowing various manipulations, transformations and analysis on geometry, construction operations can better utilize process modeling and simulation approaches for other man-made systems, such as manufacturing, communication, electrical systems.

2D drawings are the predominant representation of the finished facility which can provide minimum idea of the real construction work. The availability of 3D geometric models for project management can open the door of new possibilities. Effective use of the 3D geometric models provide better understanding of the construction processes with geometry in mind.

VISUALIZATION AND SIMULATION SYSTEMS
Construction operations are visualized and simulated in many ways. The choice for implementing a proper system depends on the degree of visualizing the construction site, degree of complexity in construction works, information available and information necessary and insights to be visualized.
Dynamic construction visualizer

Dynamic construction visualizer or DCV is intended to be used in conjunction with a wide variety of simulation tools using 3D models created in an equally wide variety of CAD modeling programs. It is neither a simulation tool nor a CAD modeling tool. It can be implemented as a Microsoft Windows application and can operate files which are written in DCV language. The DCV graphically illustrates the specific modeled construction operation (Fig. 1) based on the data taken from logged on simulation model. Simulation model creates DCV animation when they run. Simulation language has to be simple enough to generate model trace file easily but at the same time it has to be strong enough to illustrate the dynamic operation of complex construction tasks.

DCV is implemented as a “post-simulation” visualization tool which can provide the following services to the operator:

- It maintains a simulation clock whose speed can be controlled by the operator.
- The operator can put himself in any vantage point of a 3D virtual workspace so he can navigate the place like actually he can do in real world construction site.
- User can jump into forward or backward to any desired position by specifying a past or future time value in the clock.
- The operator can observe specific construction tasks through the animation, can pause anytime and make static observation to find out disparity or constraints on the task.

Although the DCV system can depict the real dynamic motion of construction equipment e.g. dump trucks, excavators, cranes, backhoes etc. but it cannot depict the transformation states of simulation objects during visualization. It illustrates the visualization based on certain completion stages e.g. assembling, loading, unloading etc. but it does not support the visualization of physical deformations of simulation object or its environments. For instance, when an excavator digs the earth, DCV cannot depict the concrete deformation, concrete flow into the concrete pump, bending of rebar or cutting of blocks.

Augmented Reality Applications

The recent development of computer technology and miniaturization of computer hardware allow for the integration of augmented reality in construction works. This system consists of a see-through head worn display which is capable of overlaying graphics and sound of real world activities. It can track users and objects in space and sends visual information. This system is written by C, C++ and CLIPS programming language and can run in Unix operating system.

It shows the users portions of a building which are hidden behind structural obstacles and enabling users to see additional information of the hidden objects. The user can stand on a position within a room and can see the graphical representation of a model prototype and tracks the orientation data by an ultrasonic tracking system.

Augmented Reality Applications

The recent development of computer technology and miniaturization of computer hardware allow for the integration of augmented reality in construction works. This system consists of a see-through head worn display which is capable of overlaying graphics and sound of real world activities. It can track users and objects in space and sends visual information. This system is written by C, C++ and CLIPS programming language and can run in Unix operating system.

It shows the users portions of a building which are hidden behind structural obstacles and enabling users to see additional information of the hidden objects. The user can stand on a position within a room and can see the graphical representation of a model prototype and tracks the orientation data by an ultrasonic tracking system.

Navigational Approaches

There are many systems for outdoor navigation systems already being used globally. These systems are categorized into two – Network Based and Handset Based. In network based system also known as network dependent system signals are taken by mobile
devices from mobile network covering its area of presence. Handset based which is network independent can provide location identification information even if the network is not available in that particular location. This form is very advantageous and most frequent used method from this category is Global Positioning System (GPS).

GPS can achieve cm-level kinematic positioning accuracy, but with some major constraints. First and foremost the use of GPS signals for indoor positioning poses difficult challenges, due to the very weak signal levels. Indoor positioning using high sensitivity GPS receivers cannot be guaranteed in all situations, and accuracies are typically of the order of tens to hundreds of meters at best. Indoor positioning technologies set the constraint of a limited coverage range, such as a building or other confined spatial area (for example, a stadium or an exhibition).

A system developed based on GPS is Locata by Locata Corporation. Locata is a positioning technology that is designed to overcome the limitations of GPS and other indoor positioning systems currently available. It has invented a time-synchronized pseudolite transceiver called a LocataLite. A network (Fig. 3) of LocataLites forms a LocataNet, which transmits GPS-like signals that have the potential to allow point positioning with sub-cm precision (using carrier-phase) for a mobile unit (a Locata).

Another system to overcome GPS’s constraint in indoor navigation is Active Badges (Fig. 4) developed at AT&T Cambridge. A small infrared beacon is worn by every person or elements and the badge emits a globally unique identifier every 10 seconds. A central sever collects this data from fixed IR sensors around the building, aggregates the data into a central repository, and provides an API for applications to take advantage of the data. An extension to this work used by the Xerox ParcTAB system implemented a 360-degree infrared “deathstar” to address the problem of IR directionality.

**Fig. 3. Indoor positioning with Pseudolites.**

**Fig. 4. Active badges for sending location data**

**PROPOSED SYSTEM FOR VISUALIZATION AND SIMULATION**

Navigation based visualization and simulation technologies can be possible solutions for avoiding construction project failures due to poor communication, poor planning and poor estimation. The whole process of the construction with such technologies can be summarized (Fig. 5) as follows -

1. **Planning stage**

In this stage project planners and decision makers along with the customer will survey the project site and make necessary and optimum planning for the construction design. Augmented reality system can be fruitful in this stage. Customers will make their demand and the designers will justify the feasibility of the demand according to the resources available. Designers can use the site’s GPS data to observe along with the on-site physical visit. After getting raw data from site and customer and processing the data they can finalize the project estimation and propose the final design.

2. **Ongoing project monitoring stage**

In this stage project supervisors and other observers can closely monitor all real time construction work with minute level details. Indoor positioning system with pseudolite and active badge system can help in this stage. Pseudolite based navigation can be used to locating the cm-level accurate positioning of elements, fittings, joints etc. and active badges can help the project supervisors to monitor if the equipment are reaching and available at the desired location in correct quantity. Individual construction tasks can be simulated by the DCV system when existing DCV models limitations can be overcome by using data from pseudolite activity. This phase also allow efficient real time data extraction, execution and recording of the construction activities.

3. **Correction stage**

The data found in project monitoring stage can be used to find out any irregularity in the construction work instantly and enable the supervisors to make immediate correction of the problems. This removes the time delay and cost overrun due to the pause in construction task.
CONCLUSION

In general the practice of visualization and simulation systems in construction works are very limited by the practitioners and the adoption of these systems are very slow in the construction industries. This can be said happens due to the lack of enough number of researches in construction simulation systems, complexity of the construction works and lack of much effort to prepare models for simulation systems. However to avoid the common failures occurring repeatedly in big construction projects, it is obvious that proper visualization and simulation tools should be implemented. The positive side is, like other production industries like car manufacturing or beverage productions, construction works also consist of common and repetitive tasks. So, systems should be developed to visualize and simulate these common tasks. The paper reviewed and intended to combine few technologies and to suggest a possible system to make the construction task more efficient. Successful implementation of the suggested method can be practiced and more researches can be carried out to investigate more deeply into the utilization of the systems with highly autonomous, intelligent construction and manufacturing systems.

References