Potential assessment of immersive visualization for better cost definition during semi-detailed engineering phase

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Abstract. Traditional method of defining design and cost scope of project between the client and consultant requires repetitive updates and visualization. However, lack of proper visualization persists during this phase i.e. semi detailed engineering. This results in longer cost blackout periods and weaker cost control leading to less accurate budget scope. Mostly drawings and (sometimes) scaled models are used in getting feedback from client. With the emergence in the visualization technology, it is possible to get immersed in a full-scale interactive virtual environment and experience everything like it is happening in real. This technology has a potential to present things in “interactive- immersive-physics” enabled environment as a way to assist in cost and design appraisals happening between client and consultant. This paper aims at reviewing potential of “Immersive visualization” and summarizing the factors that can be controlled using the same in construction projects to improve cost engineering process during semi-detailed engineering phase. The study will provide knowledge base for implementing virtual reality into construction project scope definition. Review, potential best practices alongside inputs from field professionals and experts will be utilized to achieve the objectives of this study.

Virtual-Reality, Cost Engineering, Construction Industry, scope definition
1. Introduction

Akinsola et al. [1] states that design discrepancies are omissions, adjustments to original concept and scope of the project after the contract of the project is awarded. It may lead to adjustment to the total cost and time of the project and it happens in almost all the projects [2]. According to Park [3] the discrepancies in the projects are changes in original plan, specifications which results in the quality of work, change in scope, increase in budget and time of the project. According to Love Smith & Li [4]; Love [5], design changes occur due to scope incorrectly executed the first time leading to extra efforts/ rework to achieve the desire result. Due to complex and dynamic nature of construction industry projects there are more risks and uncertainties involve in the project [6]. Love [5] stated that the work done against the design discrepancies claims account for almost 50% of the project cost overrun.

Semi-detailed engineering is the combination of conceptual and schematic phase. It is where concept is developed and understood by stakeholders. Architects and consultants try to understand the requirements of clients, its where soil reports are generated, plans and elevations are developed specifying the major architectural details and general structural details and sent for further structural detailing etc. this is where engineer’s estimates are developed and materials are decided. Any error occurring at this stage is more likely because of the lack of visualization. If concept is not visualized and understood, it can have daunting effects as every stakeholder will have a picture of end result according to their understanding leading to not being able to achieve desirable results, dissatisfaction of client, numerous changes in design, time delay, cost overruns because sometimes these changes are identified at much later stages which leads to increase in budget.

With the increase in technology specifically Virtual Reality technology which is growing rapidly its now very easy to just not only visualize but also fully immersed into an interactive environment. This virtual world makes you think as if it is happening in Real. Virtual reality is already being used not only in so many different fields but also in different aspect of construction projects. Virtual Reality has been widely seen for health and safety trainings, architecture walk through, remote virtual sites to see work progress etc. Hence this study aims at identifying the potential of immersive visualization for better cost definition during semi-detailed phase.

There are limited researches available that address the errors occurring during the semi-detailed engineering phase of the project. Hence this study aims at critically reviewing the errors that occur during semi-detailed phase, confirming those errors from industry and then proposing immersive visualization as a solution to avoid such issues.

2. Objective and Scope

The objective of this study is:

- To reviewing potential of “Immersive visualization” and summarize the factors that can be controlled using the immersive visualization in construction projects to improve cost engineering process during semi-detailed engineering phase.
- To provide knowledge base for implementing virtual reality in construction projects for better cost definition during semi-detailed engineering phase.

Study scope is limited to semi-detailed engineering phase of construction building projects.

3. Methodology

Figure 1 provides methodology chart. From the extensive literature review the papers that addressed problems due to design errors were selected and only those errors were considered which are likely to occur at semi-detailed engineering phase. Also several papers were reviewed which used BIM technology, Virtual reality systems to solve visualization problems on construction projects. Once the design discrepancies were identified from literature review, non-structured interviews from focus group of industry experts from were conducted for conformance of the errors identified from literature.
Considering the factors identified from literature review, and thereafter duly conformed by the experts, conclusions and recommendations for using Immersive visualization for Semi-Detailed Engineering Phase has been proposed. This is a critical explorative research study which will provide with the road map to follow for future reaches in this regard.

Figure 1. Research Methodology flowchart

4. Literature Review
4.1 Virtual Reality (VR) Systems for Providing Immersive Visualization
Virtual Reality technology has two major classifications 1) Individual Immersive Visualization Systems and 2) Group Immersive VR system. However due to the emergence of this VR technology we cannot limit the number of classifications but in most of the literature these two types are most discussed VR systems.

4.1.1 Individual Immersive Visualization Systems
This system functions on computer workstations that are customized for Virtual Reality hardware and software. This type is very popular in providing an interactive environment. The user is immersed in the environment by wearing the head mounted display (HMD). This system is specifically equipped with specific software and hardware that lets an individual experience interactive environment. Figure 2 (Left) shows picture of such a system available at the NED University Virtual Reality Center.

4.1.2 Group Immersive Visualization VR system: The projection VR system is based on a Corner Cave-in concept that has the capability (both from software and hardware perspective) to provide a virtual-cum-immersive experience to a group of people. An immersive virtual environment is created around the position of the user’s location. As the position of the user changes, his/her position in the virtual environment also changes. Due to the real-time capabilities, immersive VR is believed to be advantageous over the desktop-based VR system. Figure 2 (Right) shows picture of such a system available at the NED University Virtual Reality Center.

Figure 2. Individual Immersive Visualization Systems based VR system (Left)
Group Immersive Visualization VR System (Right)
(Source: NED University VR Center)
4.2. Prior studies regarding error factors during engineering phase and their impacts

According to Hamzah Abdul Rehman [7] almost all the construction projects go through different types of design revisions from semi-detailed phase to construction of project. As these are assorted changes hence the impact is variable; it can be huge or negligible. But since the impacts are always underestimated by the construction practitioners (professionals), it is seen that these changes lead to cost overrun, schedule delay. A study by Chang [8] has reported that as a result of changes in design, cost is seen to be increased by 24.8% and schedule by 69% based on the sampled projects in California. Another study by Chang, Shish and Choo [9] mentioned that changes have resulted in an increase in re designing cost of 2.1% to 21.5% and on average of 8.5% of the construction change cost.

It is important to identify the causes of design errors, the impacts that can be occurred due to it at an early stage of the project so that the project performance, phase, its cost & time can be effectively inhibited. Lopez, R. et.al [10] in his paper stated that it is common to see discrepancies in design pertaining to architectural detail, structural detail, quality of construction project. Technical errors occur when you fail to correctly follow the concept or schematic design of the project. The impact of errors due to design is the cost exceeding the defined budget, utilized facility, rework for the business process is disturbed and investment generated cannot be used properly [11].

As it is a known fact already that for effective communication in a semi-detailed engineering phase a good level of understanding of scope and specification is required among all the stakeholders. It is the main objective for consultants and clients that the design phase is well understood by all the stakeholders [12]. According to Hamzah Abdul Rehman [7] Sambasivan & Yau [13]; Alaghbari et al. [14];

1) Improper planning,
2) Slowness in decision making,
3) Cost and time overrun

4.3. Potential of immersive visualization technique in construction building projects

There are several researches that have been conducted on the adoption of the Virtual Reality in the construction and building industry which show that mostly virtual reality tools and displays are used for design reviews, scheduling of the project activities, coordination of detailed design, also used for simulation purposes and marketing of the project [15]. Researches concentrating on assessing the value of VR tools and displays for various cases demonstrated that VR systems are capable of generating incentive for the task group by encouraging powerful correspondence, enhancing meeting profitability and soliciting improved feedback [16]; [17]; [18]. VR technology improves communication for stakeholders across the construction project due to its great visualization leading to much better understanding of project. AEC management professionals have started recognizing the importance of virtual reality and its usability in construction projects because it makes easier for all key players to visualize designs prior to construction which helps cut the cost of material and reduces rework also helps in hiring the minimum number of staff required for the project [19]. Virtual environment lets construction project stakeholders roam around the building, visualize each element and evaluate the design and make change then and there resulting in saving time and cost of building it again. An immersive environment can help in creating construction project sequence hence improving the project planning, can help visualize the safety measure on site, therefore can provide input for construction onsite health and safety environment. The unlimited walkthroughs can let stakeholders imagine the end result. Thabet, W., Shiratuddin, M.F. & Bowman, D. [20] reported a study of Japan where three case studies were conducted to investigate Japanese house builders’ use of VR. The findings of the study were that Japanese house builders have understood the potential of Virtual Reality in construction and have been using Virtual reality technologies for over three to four years.

4.4. Factors attributed to lack of visualization

The authors were able to find out various actors that can occur in semi-detailed engineering phase, and can be attributable to lack of visualization. Such factors can lead to various impacts during the later stages specifically during construction phase. Moreover, potential improvements that can be incurred through use of immersive visualization were also defined. All this information is provided in following Table 1.
Table 1. Factors attributed to lack of visualization during semi-detailed engineering phase

| Code | Factors attributed to lack of visualization | Effect of lack of visualization | Potential improvement if immersive visualization is used |
|------|---------------------------------------------|---------------------------------|--------------------------------------------------------|
| 1.   | Client has unclear scope definition because he cannot visualize exactly what designer has in his mind about the project as consultants use 2D drawings. | Rework during construction phase due to client requirement(s) during construction phase, once he/she finally starts visualizing the project. | Development of reasonable and logical design installation sequence |
| 2.   | Inexperienced designer/Architect hired on the project unable to visualize project’s concept resulting in mistakes in drawings, and design etc. leading to extra work. | Design errors occurred due to lack of 3D visualization | Easy to comprehend complex spaces, objects, etc. |
| 3.   | Lack of technical exposure of the client unable to visualize project’s concept resulting in mistakes in drawings, and design etc. leading to extra work. | Changes in (architectural) design requirements as requested by the client once he/she finally starts visualizing the project. | Easy to insure that the needs and requirements of the construction project are implemented in the design |
| 4.   | Lack of visualization of project’s quality. | Difference from desired quality as perceived by the client during conceptual and semi-detailed engineering phase. | Improved decision making ability |
| 5.   | Client’s demands exceeding the budget because he is unable to visualize what can be done within allocated space of the project and in his budget. Hence he makes unachievable requirements. | Disputes among stakeholders due to rework, scope change, design errors, quality reductions etc. as generated based on lack of visualization. | More realistic and accurate in detail design |
| 6.   | Absence or improper visualization of the vertical dimension of buildings, and comparison between levels of buildings. | Litigation as a result of disputes due to lack of visualization. | Visual inspection of building elements can help designers find design errors for e.g. load bearing wall and column tend not to overlap from story to story. |
| 7.   | Difficulty in visualizing the comparisons between levels of buildings | Delay in project duration due to rework, scope change, and design errors, quality reductions etc. as generated based on lack of visualization. | Easy to visualize the comparisons between levels of buildings |
| 8.   | Unclear concept of the project outcomes. What is required, what needs to be done, how will it be design, etc. | Varying responses to RFI generated by the contractor due to varying understanding of concept by the client at different stages of design development. | Clear idea about the project that what are the requirements, what will be the outcomes, etc |
| 9.   | Design errors due to lack of visualization of the concept | Increase in cost of project due to aforementioned or any other impacts caused by lack of visualization during early stages of project design development. | Less deviation from the budget and time allocated to the project due to less deviation from the originally decided concept of the project. |
| 10.  | Consultants using 2 different sets of drawings existing drawings to convince clients and new drawings for construction which leads to design discrepancies and changes in scope at later stages. | Improper planning of execution | Better coordination between stakeholders. Designs can be changed easily if any errors is identified and no old or already existing drawings will be used |
| 11.  | Lack of integrated visualization of architectural details | Safety issues on site. | Integrated visualization of architectural details |
5. Conformance from Focus Group of Industry Experts

After the factors were identified from literature next in line was to form focus group and interview experts from industry who belong to consultant, client and contractor side to avoid biased and vague response. Four experts were identified to form the focus group. These included 2 clients, 1 consultant and 1 contractor. Following Table 2 provides the brief demographics.

**Table 2. Focus Group Demographics**

| Expert No. | Experience | Area of Work                | Highest Degree                              | Stakeholder Type       |
|------------|------------|-----------------------------|---------------------------------------------|------------------------|
| 1          | > 20 years | Building Design             | Masters in Structural Engineering           | Design Consultant      |
| 2          | > 11 years | Building Construction       | Bachelors in Civil Engineering              | Public Client          |
| 3          | > 12 years | Building Construction       | Masters in Project Management              | Contractor             |
| 4          | > 13 years | Building Construction, Cost | Masters in Construction Management          | Private Client         |

The focus group experts were asked about the occurrence of factors identified in literature review, their effects and potentials based on their own projects experiences. Majority of the experts selected have never used 3D models for their projects let alone virtual reality technology so it was easy for them to relate to the problems identified in literature. Following Table 3 provides details of conformity by the experts included in the focus group. The table shows the response of all the experts for each factor, its effects and its improvement identified through literature review. Expert 1, 2, 4 were from Pakistan’s construction industry. However, expert 3 was from an international contracting firm hence the difference in answers can be seen as the practices are different in both countries.

**Table 3. Experts conformance about the integration of immersive visualization for cost definition during semi-detailed engineering phase**

| Code | Expert 1 | Expert 2 | Expert 3 | Expert 4 |
|------|----------|----------|----------|----------|
|      | Factors  | Effects  | Improvement | Factors  | Effects  | Improvement | Factors  | Effects  | Improvement | Factors  | Effects  | Improvement |
| 1.   | √        | ×        | ×          | √        | ×        | ×          | √        | ×        | √          | √        | ×        | ×          |
| 2.   | √        | ×        | ×          | √        | ×        | √          | √        | ×        | √          | √        | ×        | ×          |
| 3.   | √        | ×        | ×          | √        | ×        | √          | ×        | ×        | √          | ×        | √        | √          |
| 4.   | ×        | ×        | ×          | ×        | ×        | √          | √        | ×        | √          | √        | ×        | √          |
| 5.   | ×        | ×        | ×          | √        | ×        | √          | √        | ×        | √          | ×        | ×        | √          |
| 6.   | ×        | ×        | ×          | √        | ×        | √          | ×        | ×        | √          | ×        | ×        | ×          |
| 7.   | √        | ×        | ×          | √        | ×        | √          | √        | ×        | ×          | ×        | ×        | ×          |
| 8.   | ×        | ×        | ×          | √        | ×        | √          | √        | ×        | ×          | ×        | ×        | ×          |
| 9.   | ×        | ×        | ×          | √        | ×        | √          | ×        | ×        | ×          | ×        | ×        | ×          |
| 10.  | ×        | ×        | ×          | √        | ×        | √          | ×        | ×        | ×          | ×        | ×        | ×          |
| 11.  | ×        | ×        | ×          | √        | ×        | √          | ×        | ×        | ×          | ×        | ×        | ×          |

6. Discussion on Focus Group Findings

All the experts (4 out of 4) agreed that Inexperienced designer/Architect hired on the project unable to visualize project’s concept resulting in mistakes in drawings, and design etc. leading to extra work, Absence or improper visualization of the vertical dimension of buildings, and comparison between levels of buildings, Lack of integrated visualization of architectural details and majority of the experts (3 out
of 4) agreed that Client has unclear scope definition because he cannot visualize exactly what designer has in his mind about the project as consultants use 2D drawings. Lack of technical exposure of the client unable to visualize project’s concept resulting in mistakes in drawings, and design etc. leading to extra work, Client’s demands exceeding the budget because he is unable to visualize what can be done within allocated space of the project and in his budget. Hence he makes unachievable requirements, Absence or improper visualization of the vertical dimension of buildings, and comparison between levels of buildings, Design errors due to lack of visualization of the concept and Lack of integrated visualization of architectural details indicating that lack of visualization contributes immensely in creating hurdles for the completion of a construction project. For the effects due to lack of visualization all the experts (4 out of 4) accepted that Rework during construction phase due to client requirement(s) during construction phase, once he/she finally starts visualizing the project, Design errors occurred due to lack of 3D visualization, Changes in (architectural) design requirements as requested by the client once he/she finally starts visualizing the project. Difference from desired quality as perceived by the client during conceptual and semi-detailed engineering phase and Varying responses to RFI generated by the contractor due to varying understanding of concept by the client at different stages of design development. And majority of the experts (3 out of 4) recognized the fact that the cost of project increases due to aforementioned or any other impacts caused by lack of visualization during early stages of project design development and Improper planning of execution. This indicates that the effects of lack of visualization can be really daunting for the construction projects resulting in constant changes throughout the project lifecycle, errors in design causing rework and reduction in the quality of the project, disturbance in the planning of construction and impact on cost of the project. When asked about the potential of implementing the immersive visualization (virtual reality technology) on construction projects all the experts (4 out of 4) agreed that this technology if implemented will make it Easy to comprehend complex spaces, objects, etc., Easy to insure that the needs and requirements of the construction project are implemented in the design, help in Visual inspection of building elements can help designers find design errors for e.g. load bearing wall and column tend not to overlap from story to story, give a Clear idea about the project that what are the requirements, what will be the outcomes, etc., will improve coordination between stakeholders. Designs can be changed easily if any errors are identified and no old or already existing drawings will be used and provide Integrated visualization of architectural details Also, when they were asked if they would implement virtual reality technology in their practice expert 1 and 2 stated that they are satisfied with the way the information is distributed to them without VR or 3D models. However, expert 3 and 4 seemed excited about implementing this technology in the construction projects but expert 4 emphasized that this would be beneficial for project planning only, it will not have an impact on cost unless it’s applied during detailed construction project.

7. Conclusion and Recommendation

The discussion clearly shows that both data extracted from literature review and expert opinions it can be said that lack of visualization has variable impacts and all of them in the end create a huge impact on the cost of project and also the utilization of immersive visualization in the construction projects can help in curbing this problem. Based on the information collected from extensive literature review and its conformance from industry experts it is safe to say that if real time projects are modelled on 3D modelling software and then using virtual reality tool can be made interactive for all the stakeholders to get immersed in that environment and identify mistakes on the spot to avoid discrepancies at later and crucial stages.

Project constructed this way would let stakeholders to identify design and construction challenges; Define scope of works. According to this 3D models of building components, temporary work facilities and plants will be created and virtual meetings will be carried out to check dimensional conflict. The Simulated planned construction process will validate the construction sequence, help in finding the time space conflict, optimize resources utilization and let professionals try different alternatives by making changes and visualizing the and there to identify any discrepancies. This will not only help in identifying problems on the spot at the initial stage to avoid huge changes at later stages but it also provides with the rich environment with all the properties needed to create construction sequence and plan the project and would stop project from exceeding the budget of the
project. Hence this will act as a knowledge base for both contractors and consultants for better cost definition during semi detailed construction phase as now with simulated environment it will become easier for them to try what-if scenarios and improve decision making.

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