Summary for CIFE Seed Proposals for Academic Year 2020-21

Proposal number:	2020-08
Proposal title:	The Next Design Workflow: Transforming Project Workflow Through VR-Augmented Design Review
Principal investigator(s) and department(s):	Martin Fischer -Civil and Environmental Engineering Renate Fruchter -Civil and Environmental Engineering
Research staff:	Simge Girgin, Graduate Student, Civil and Environmental Engineering
Total funds requested:	**$ 60, 647**
Project URL for continuation proposals	**http://**
Broad Category Addressed in this Research	Experience improved for all stakeholders
Project focus area addressed by proposal	Project Collaboration, Team Collaboration**.**
Stakeholders' benefitted by the research	Owners, Designers and Builders.
Expected time horizon to impact the industry	2 to 5 years
Type of research	Exploitation
Abstract (up to 150 words)	**Observed Problem**: Project workflow is punctuated by scheduled formal project review meetings. Design teams experience response latency, decision wait-time, and increased lead time due to lack of activity transparency and collaboration between schedule formal project review meetings.. **Primary Research Objective and Solution**: This seed research aims to: 1.Formalize project workflow transformations through VR-augmented design reviews 2.Develop: -Protocol that defines the VR use based on Why-Who-When-How. -Framework to analyze what VR-augmented design reviews changes in design workflow. -Preliminary prototype of integrated VR-augmented design workflow. **Proposed Research Approach and Methodology**: The proposed study will use an iterative process that applies the Observe-Analyze-Intervene method. 1.Observe project design workflow – starting with a state-of-practice scenario. 2.Analyze the workflow using a qualitatively and quantitatively multi-method approach. 3.Intervene by introducing a VR-augmented collaboration protocol, repeat step 1-3.

Business Problem

Virtual reality (VR) technologies have been used in the design stage of Architectural, Engineering and Construction (AEC) projects since early 2000s. Several studies and business cases show that leveraging virtual reality tools improves the design review processes by bringing stakeholders into the same virtual room, increasing the engagement among participants, and facilitating the informed decision making. Given that the design review meetings are important milestones in the overall design process, detailed analysis of VR benefits is well analyzed and understood for design review meetings. However, design teams experience response latency, decision wait-time, and increased lead time due to lack of activity transparency and collaboration between formal design review meetings. Hence, it is critical to analyze how VR-use adds value to the collaboration and decision-making during the overall design process in AEC projects not only during formal design review meetings. We believe that this lack of analysis of the value generation with VR use is a major roadblock against eliminating response latency, decision wait time and increase lead time by fully utilizing virtual environments in the design process.

Architectural and engineering design is an extensive process that necessitates collaboration of different stakeholders, including architects, owners, structural engineers, mechanical, electrical and plumbing (MEP) engineers, construction managers, and several other decision-makers. During the design process, the use of VR tools brings significant benefits to not only formal design review meetings with project decision-makers but also to the informal team interactions and facilitates multidisciplinary design collaborations (Fruchter, 2018). Simge Girgin (the graduate research assistant proposed for this research project) experienced the importance of informal design collaborations while working with her globally-distributed cross-disciplinary team in the AEC Global Teamwork class. The goal of the team was to virtually design and build a 30,000 sq. ft. educational building in Puerto Rico in a challenging zone with earthquakes and hurricanes. Given the challenges of the project, the use of digital visualization technologies such as VR are essential in the design process. However, the team did not leverage VR use at first. Instead, they met in VR for only formal design review meetings once in a week to review the current design, plan their tasks and determine dependencies (Figure 1).

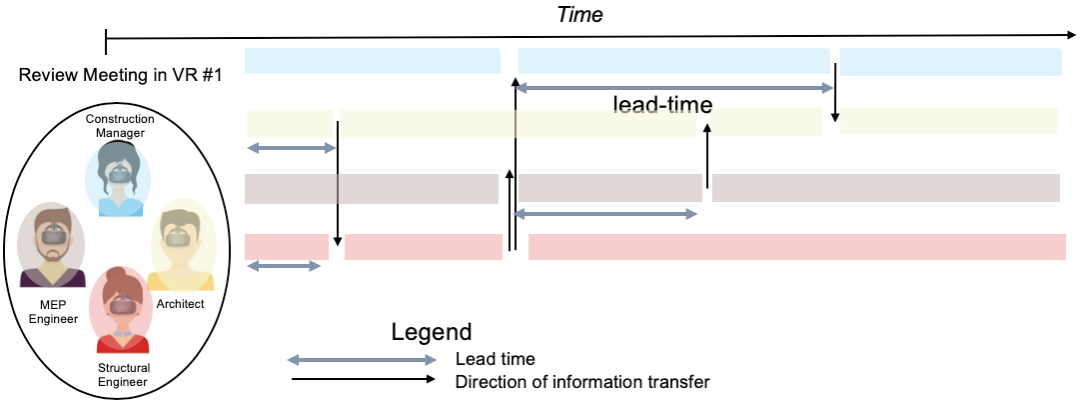

Figure 1: Planned activities and dependencies in the review meeting in VR.

Even though the team believed that the schedule they prepared was accurate, the architect encountered an issue in the layout that resulted in a response latency that would affect all of the downstream disciplines. Other disciplines waited for the architect to resolve the issue before they

continued. As a result, they observed a 40% increase in the decision wait-time and total lead-time of activities and lost three days of their design time (Figure 2).

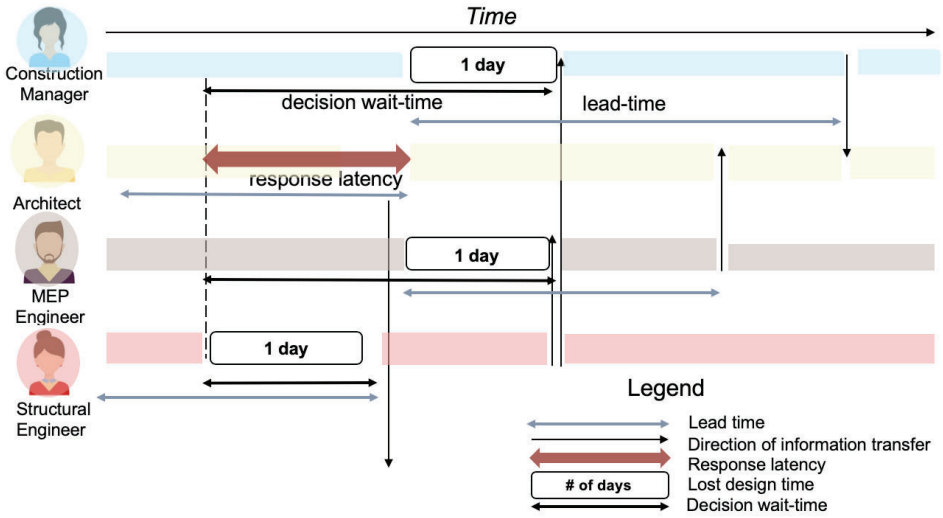

Figure 2: Actual workflow after the team experienced response latency.

Instead of waiting for the architect, other disciplines could have met with the architect in VR. They could have contributed to the solution directly by reviewing the problem in detail, creating different solutions, and selecting the best solution together. As a result, they could have eliminated response latency, increase in lead-time and decision wait-time. The team learned their lesson and afterwards used VR any time they had a design issue. However, the team did not use a standardized approach to utilize VR. Instead, they used trial and error approach to see what works for their team. In the industry, the problems are more complex, and any delay is less affordable. Hence, it is critical to standardize VR use within the team with protocols and assess the change that VR brings to the design workflow to better understand its value. With this proposed research, we aim to answer the following questions:

1) What is a VR-augmented design review protocol that would answer how, when, why, and with whom to use VR and formalize the meeting in VR practice for design teams?

2) How would VR-augmented design review sessions transform the interdisciplinary design workflow?

Theoretical and Practical Points of Departure

Military, manufacturing, and entertainment industries saw the earliest examples of VR use as described by John A. Adam in 1993. The early-adopters such as NASA, Boeing, Caterpillar, and Chrysler primarily used VR for facilitating the engineering design stage by creating a dynamic sense of models (Adam, 1993). Although the diffusion of VR technologies into the AEC industry was found to be relatively slow compared to the manufacturing industry, potential applications were listed for architectural and engineering design in the late 1990s (Bouchlaghem et al., 1996).

The focus of the architectural and engineering design process is on the continuous evaluation of proposed design ideas and engineering solutions (Castronovo et al., 2013). VR facilitates the design evaluation process by decreasing the effort needed to understand a design (Liu et al., 2014) and increasing the sense of presence and realism (Castronovo et al., 2013; Fruchter, 2018) through field of view changeability (Alshaer et al., 2016). It increases the engagement (Berg 2014; Fruchter,

2018), harvests participants project knowledge, and promotes creativity in the participants (Fruchter, 2018), who in turn can make more informed decisions and provide meaningful feedbacks during design review meetings.

In the Center for Integrated Facility Engineering (CIFE), the impact of immersive virtual environments on real-world project design collaboration meetings has been studied since the early 2000s. In one of the earliest CIFE studies, VR was used in the form of Computer Assisted Virtual Environment (CAVE). It demonstrated that stakeholders were more engaged in the decision-making process when participating in VR-based review sessions, not only during but after the meetings as well. It was reported that stakeholders stayed in the same room and continued their discussion voluntarily (Haymaker and Fischer 2001). Later, Majumdar et al. (2006) compared the Virtual Reality Mock-Up Model (VMM) with physical mock-up model. They reported that using VMM in the design review sessions supported quick modifications in design and decreased the time it takes to compare different design alternatives, bringing down the eight hours it usually took with the traditional review sessions to three hours. Considering these benefits, they concluded that building a VMM was worthwhile.

After several studies on design review meetings using VR in both CIFE and other academic institutions, researchers started studying the importance of activities before and after review meetings. Berg et al. (2017) analyzed the potential of virtual environment usages in advance of review meetings. They stated that clients who had a VR walkthrough before the review meeting felt more empowered to contribute to the design solutions, provide their feedback, and actively participated in discussions about design issues they previously identified. Moreover, Ventura et al. (2019) prepared a preliminary framework of procedural considerations for VR implementation, emphasizing the steps that should be followed to prepare a design review session in VR. Later, Ventura et al. (2020) developed a session protocol to ensure the effectiveness of VR in design review sessions by providing the activities at three different phases: before, during, and after the VR review session.

Unfortunately, previous research has not systematically studied the value of VR-augmented design review collaborations in the interdisciplinary architectural and engineering design workflow. Current literature also confirms this gap and points out the need for developing a framework to measure the actual value added by the implementation of VR tools in design processes (Ventura et al., 2020). To improve design processes, it is imperative to analyze the value of VR in the design workflow; in other words, the changes that VR-use brought to the design workflow.

Research Methods and Work Plan

The proposed research will be conducted in five phases. The method for the first phase will be literature review. For the rest of the phases, case studies and interviews will be primarily used to collect data and validate the study. These phases are observation of current design workflow, development of a framework to analyze the observed workflow, development and implementation of VR-augmented design review protocols, and analysis of the new design workflow and comparison with the previous workflow. Throughout the study, Observe-Analyze-Intervene research approach (Figure 3) will be used. This approach was first developed and used for data collection in design research by John Tang at the Center for Design Research at Stanford University (Tang, 1989).

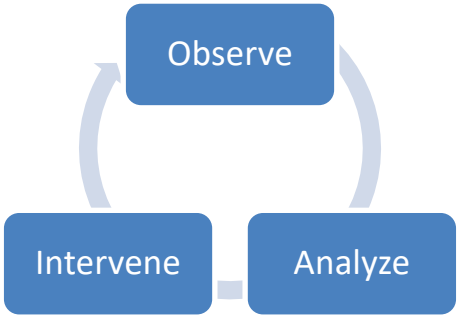

Figure 3: Observe-Analyze-Intervene research approach (Tang, 1989)

1) Review Literature

- Consolidate and structure existing literature on VR-collaboration during architectural and engineering design.
- Review workflow management studies and select qualitative and quantitative baseline workflow comparison metrics from three categories: *response latency, decision wait-time, and lead-time.*

2) Observe: Preparing the current design workflow

- Prepare the current interdisciplinary design workflow through direct observation, interviews, design plans and milestones.
- Determine the use of VR (purpose, scope, frequency, duration, attendees) in the interdisciplinary design workflow through direct observations and interviews.

3) Analyze: Develop a preliminary framework to analyze the current workflow

- Build a framework to analyze the workflow by using previously determined metrics and developing new metrics if necessary.

4) Intervene: Operationalize VR-augmented design review protocols

- Formalize VR-augmented collaboration guidelines after interviewing with design team members and answering why, how, when, and with whom to use VR would be helpful for the design team.

5) Observe and Analyze VR-augmented workflow and compare it with the previous workflow

- Observe and prepare the new design review workflow after the design team used VR-augmented design review protocols.
- Compare the new workflow with the state-of-practice workflow using the framework developed in the third phase.

Expected Contributions

- Theoretical

There are three theoretical contributions of this research. First, we will develop protocol that defines the VR use based on why, who, when and how. Second, we will build a framework to analyze what VR-augmented design reviews changes in design workflow. Third, we will identify a preliminary prototype of integrated, and VR-augmented design workflow.

- Practical

An assessment of the design workflow by using a framework will reveal what changes by leveraging VR use which can also be translated to the value addition by VR use. In this way, design teams will prepare better design workflows by considering the potential VR review sessions and plan these review sessions using the VR-augmented collaboration protocol. Also, they can organize their collaboration not only with owners and builders but also with their interdisciplinary design team. As a result, this proposed research will show a prototype of integrated, interdisciplinary VR-augmented design team workflow with decreased response latency, decision wait-time, and design lead-time.

Industry Involvement

We plan to reach out to CIFE members and invite them to engage in our seed research project by providing access to observe and/or interview project stakeholders during:

- state-of-practice project design workflow design review
- VR-augmented design workflow design review

during concept development / schematic design stage. We believe the integration of VR-augmented design review in the design workflow will directly benefit the conceptual design, schematic design and design development phases and indirectly benefit the construction documentation, procurement, administration and facility maintenance phases of the project. Therefore, we hope that CIFE members will collaborate with the research team in the preparation of design workflow, development of VR-augmented design review protocols, and application of protocols within the project design team. To date, we have maintained contact with VIATechnik.

Research Milestones and Risks

#	Milestone	Delivery Date
1	Perform literature review	July 2020
2	Collect and analyze workflow of industry state-of-practice case studies	October 2020
3	VR-augmented design review collaboration protocol is prepared and shared with the participants of case studies. Develop VR-augmented design review collaboration protocol and prototype, and share/test with case study participants as a preliminary intervention	December 2020
4	Collect and analyze VR-augmented workflow data case study	February 2021
5	Formalize preliminary framework project workflow transformations through VR-augmented design reviews	April 2021
6	Document, report, and seek further research funding.	June 2021

The following risks may impair the progress of our proposed research:

- Availability of projects in the planning phase.
- Need of investment for new VR equipment in the projects.
- Need of VR training sessions for design teams.

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