

Conversational Virtual Humans on 360-Degree Virtual Sites: Guiding Students on a Site Visit to a Mechanical Room

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ABSTRACT

Effective communication is essential for students in construction management and relevant fields. Nevertheless, very little emphasis on communication practices has been placed in the construction management curriculum, and limited communication skills are still widely found among students. Ideal construction site visits not only supplement traditional learning in the classrooms but also provide opportunities to communicate with professionals onsite. However, challenges exist that limit the application of site visits and ultimately reduce such opportunities to practice communication skills with experts on the jobsites. This research aims to help overcome the barriers by proposing a novel approach that leverages 360-degree digital sites with virtual human as conversational partners on site (iVisit-Communicate). In this paper, the design and development processes of iVisit-Communicate were described in detail, followed by a case study of its implementation on a digital site visit to a mechanical room. It was found that most students agreed that iVisit-Communicate provided them an opportunity to practice communication skills.

INTRODUCTION

Effective communication is essential for students in construction management and relevant fields to minimize or eliminate miscommunication and deliver a satisfied-quality project in their future work. Some communication skills development methods are applied in college, such as giving presentations, role-playing, and submitting assignments in audio or video form (Riemer 2002). However, very little emphasis on communication practice has been placed in the construction management curriculum, and lack of communication skills is still widely found in students (O'Donnell et al. 2011; Sheth 2015). The context in which the communication occurs directly affects how construction practitioners communicate; therefore, when training students' communication skills, it is essential to expose them to the real-world contextual problems typically found on construction jobsites. As exposure to real-world jobsites is a typical characteristic of site visits, these visits may have great potential in providing students opportunities to practice communication skills.

A construction site visit is an interactive experience that exposes students to authentic construction sites (Eiris and Gheisari 2017). It can help students comprehend construction working procedures in a real-world setting and attain a stronger and deeper learning experience. During the site visit, students can observe a real construction context, reinforce the abstract knowledge they learned in the classroom and gain a spatiotemporal awareness (Arslan 2004). Ideally, three fundamental elements compose a successful construction site visit: well-defined

learning objectives, accessible and proper spatiotemporal occasions associated with those learning objectives, and subject-matter-experts (construction professionals or class instructors) on site with whom students can have interactive communication (Eiris and Gheisari 2017). On a site visit, the expert can communicate with students about the contextual issues typically found on real sites, and increase students' awareness of available career options (Adedokun et al. 2012; Sawhney et al. 2000). Therefore, ideal construction site visits not only supplement students learning in classrooms but also provide them opportunities to communicate with professionals onsite. However, there are major challenges to conduct site visits, such as financial limitation, legal risks, time and geographical constraints (Wen and Gheisari 2020); the positive effects of site visits may also be reduced by large class sizes, not being able to see or hear in a crowded or noisy environment, and short duration of a visit (Eiris and Gheisari 2017). These factors hinder educators from organizing site visits and ultimately reduce the opportunities to practice communication skills with subject-matter experts.

To overcome these factors, research on virtual site visits has been done to provide easier access to the construction jobsites. Applying virtual site visits have been proved beneficial to visualize building structures, materials, equipment and construction activities onsite without actually making a trip to the sites (Wen and Gheisari 2020). However, the potential of implementing communication components within virtual site visits has not been investigated. In this study, 360-degree panoramas are used to render the data-rich virtual sites, and a conversational virtual human is implemented to guide the virtual site visit and communicate with students. The design and development processes of *iVisit-Communicate* are explained in detail. Additionally, the ability to deliver site visit experiences and communication practices using the *iVisit-Communicate* platform was assessed through a case study in a mechanical systems class.

MOTIVATION AND POINT OF DEPARTURE

In the construction industry, projects usually exist in a dynamic environment and involve several parties, such as owners, architects, engineers and contractors, to communicate constantly for satisfactory project delivery within budget and on time. Therefore, the communication skill is essential for construction management students. Communication significantly depends on the context, which usually involves project information and details on construction jobsites, therefore, the construction site visit is promising for students to practice communication skills as it exposes students to such real-world contextual problems. However, in current site visit practices, communication opportunities can hardly support every student due to the large class size and noisy environment. The goal of this proof-of-concept study is to explore the potential of *iVisit-communicate* in delivering site visit experience and supporting communication practice with the virtual human. In this conversational-virtual-human-guided visit (*iVisit-Communicate*), students can observe the context of a real construction site and practice their communication skills with the virtual human on a pre-designed scenario. This study can provide initial insights to understand the potential of *iVisit-communicate* as a tool for students to practice their communication skills in a construction-relevant context.

DESIGN AND DEVELOPMENT OF *IVISIT-COMMUNICATE*

The *iVisit-Communicate* platform developed in this study aims to provide students an opportunity to practice their communication skills during a site visit to a construction-relevant context. The creation of the *iVisit-Communicate* platform is composed of two processes: content design and platform development. In the content design process, two types of communication

between the students and the virtual human are designed: one-way and two-way communication. One-way communication represents the process where the virtual human introduces the jobsite and relevant learning content and students are not expected to provide feedback or make comments to the virtual human immediately. This communication simulates a common form that many site visits conduct, where the subject-matter-experts onsite guide the tour and act as the active speakers, while students act as passive listeners. Two-way communication represents the process of active conversations between the virtual human and students, where both parties would exchange ideas and information frequently with each other. In the platform development process, the 360-degree digital site is created that embedded two types of communication during the visit. In this process, 360-degree panoramas augmented with layers of information and virtual humans with animations were employed (Eiris et al. 2020).

Content Design: In this process, contents for one-way and two-way communication during the site visit are carefully designed. To define the contents for one-way communication, which mostly happens during the guided tour provided by the virtual human, it is essential to understand the goals of the site visit and identify its learning objectives. Based on the goal and learning objectives, certain locations on construction jobsites would be selected for the site visit, and the topics (e.g., certain types of construction activities, materials, or equipment) that are covered during the visit would be determined as well. Given the selected construction jobsites and topics for the site visit, multiple scenarios and contexts can be designed for one-way communication, where the virtual human guides the tour, introduces different locations onsite and acts as the active speaker.

Furthermore, the scenario that supports two-way communication and its corresponding conversational corpus are also designed based on the site visit's goals and learning objectives. In this study, a task is designed in the scenario to define the scope and the purpose of the two-way communication. Conversational corpus represents both the questions the virtual human can respond to and the content of the responses. In the task scenario, the conversational corpus is initially created based on the research team's best guesses about the sentences that will be said to the virtual human under this designated scenario. Through an iterative process of interactions with the virtual human, new conversational data is collected from users to improve the conversational corpus. In this study, the Virtual People Factory (VPF) is used to perform the iterative improvement, which is a web application that implements human-centered distributed conversation modeling (Rossen et al. 2009). In this iterative improvement process, users can communicate with the virtual human about the designed scenario based on the previously generated conversational corpus. If VPF cannot identify users' questions or provide appropriate responses, the conversational data will be marked in the VPF platform and the research team will manually improve the conversational corpus by adding users' unidentified input or appropriate responses for the input. To apply the VPF platform, it is required to upload the 360-degree panoramic environment, where the virtual human has been integrated. This process will be introduced in detail in the next section.

While the goals and learning objectives of the site visit and conversational corpus have a significant influence on the verbal communication content design for *iVisit-Communicate*, the non-verbal cues between experts and students during real-world site visits play an important role in designing the non-verbal cues for the virtual human. To understand the types of non-verbal cues that professionals or instructors onsite find mostly efficient in communicating with students, the research team observed five site visits conducted in two different construction classes. Among these five visits, the site locations, the experts who were guiding the tour, and the visits'

goals and learning objectives were all different than each other. It was observed that the most frequently used non-verbal cues of the professional or instructors were body orientation, walking, finger-pointing, and other types of hand movements. These non-verbal cues help students notice and keep focused on designated objects that are being discussed.

Platform Development: In this process, the development of the *iVisit-Communicate* platform is introduced: the creation of component (1) 360-degree digital site, generation of component (2) conversational virtual human, and (3) integration of the previous two components (Figure 1). For component (1), 360-degree panoramic images of selected locations on construction jobsites (decided in the previous section) are captured using the 360-degree cameras and authored into equirectangular scenes using computer software. Then, game engines (e.g., Unity and Unreal) that support 3D graphics can be used to render the 360-degree panoramic environment. The equirectangular scenes imported to the game engine are projected into spherical visualization of the jobsite, where the user's perspective is in the middle of the sphere. Finally, visual augmentations are superimposed over the 360-degree environment to provide users with more detailed information about certain contexts onsite.

For component (2), the 3D character can be modeled as a human body with computer-generated representations using graphical software, such as Adobe Fuse CC. The animations enabled the virtual human to make gestures and other movements necessary for the designed conversational corpus. In this study, the included animations can mimic human's hands and body movements for waving, walking, talking, pointing forward and behind, and idle position, which is highly corresponding to the most frequently applied non-verbal cues in real-world site visits. Based on the communication contents generated by the previous section, audio files can be created using online text-to-speech tools. These tools can synthesize natural human voices. The 3D characters, animation, and audios files are imported to the game engine to be integrated as an animated virtual human with a natural human voice.

The *iVisit-Communicate* integrates the previous two components in the game engine, then the virtual clipboard and the input box are introduced to the platform. The virtual clipboard contains three interactive buttons that allow users to keep track of the learning objectives, review the learning contents and move to other scenarios on this site. The input box allows users to type in their questions or comments in the task scenario. Once users hit the sent button, a loading circle would appear while users wait for the virtual human's response. The virtual human's responses are in audio format. Communication with the virtual human is achieved using Google's Dialogflow API as a conversational system. It allows users to ask technical questions and get appropriate responses back from the virtual human. The questions and the responses are associated with specific tasks in a pre-designed construction scenario, and the audio files are pre-imported to the game engine.

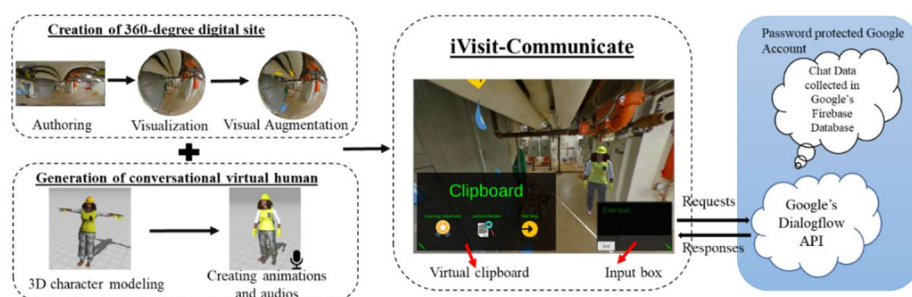


Figure 1. Development of *iVisit-Communicate* Platform

IVISIT-COMMUNICATE IN A MECHANICAL SYSTEMS COURSE

The Implementation Process: a case study was conducted to illustrate the capability of *iVisit-Communicate* in a mechanical systems course. Mechanical, electrical, and plumbing systems subject was observed as a core class in the construction management area with the highest portion of site visits (Eiris Pereira and Gheisari 2017). A site visit to a mechanical room was created to provide application knowledge of mechanical and plumbing systems. The mechanical room is usually narrow and filled with equipment, pipes, and ductworks that create massive noise, which is difficult to organize for a large group of students to visit. After reviewing the class materials and confirmed by the class instructor, the site visit goals and objectives were identified.

Fifty-two 360-degree panoramas were captured in a mechanical room of an institutional building located at the University of Florida. Based on the goals and learning objectives, five panoramas were selected for this site visit. Two of them contained essential devices and ductworks in the HVAC system, and another two contained essential devices and pipes in the plumbing system. One panorama was used for the task scenario, where the students were asked to identify the function and diameter of a leaking water pipe. This task was carefully designed to constrain the scope of conversations. The conversational corpus was initially created based on the research team's best guesses about the relevant sentences that will be said under this task scenario; then, the conversational corpus was iteratively improved by exposing to 32 students to collect more variants of relevant sentences and make the corpus more comprehensive. Random questions and irrelevant questions were discouraged to maximize the possibility of students' receiving a valid response. If the conversational corpus didn't recognize students' relevant sentences, a response 'sorry I don't understand, can you say it another way?' would be sent to encourage students to rephrase the sentences. In this study, the game engine Unity was employed to develop the *iVisit-Communicate* platform. When the design and development processes were finished, *iVisit-Communicate* was built as an executable file.

Experimental Methodology: To evaluate *iVisit-Communicate*, students with various academic backgrounds were recruited. Due to safety concerns during the COVID-19 pandemics, the entire experiment process was designed to be conducted remotely. *Qualtrics* online surveying platform was used to distribute experiment surveys and *iVisit-Communicate* platform. The platform was zipped and uploaded to the cloud for easier distribution. The link to download the *iVisit-Communicate* platform was embedded in the *Qualtrics* survey.

Recruited students would have access to the *Qualtrics* survey link. As this experiment was conducted remotely, students were asked to use their laptops or desktop computers to finish the experiment. Considering any real-time meeting software would consume computing power and Internet speed, to maximize the *iVisit-Communicate* performance on different computers, the research team decided to have students finish the experiment independently without meeting with the research team in real-time. The primary researcher's email address was provided in the survey to provide students access to technical help from the researcher if they encountered any difficulties. The experiment procedure was explained in detail in the consent form at the beginning of the *Qualtrics* survey.

Students need to 1) fill out a pre-visit survey, then 2) download a zipped folder which includes an executable file of the *iVisit-Communicate* platform and experience the virtual site visit. A tutorial video was recorded and embedded in the *Qualtrics* survey to instruct students how to download and open the platform. During the virtual site visit in *iVisit-Communicate*,

students would first be introduced with the introductions of how to use the platform. Then, students would visit a mechanical room, and a virtual construction professional would introduce equipment and devices that are associated with the HAVC system and plumbing system in this room. Finally, students would be asked to solve a task, where students should actively communicate with the virtual human to gather information and seek feedback. Communication is a soft skill and can hardly be directly measured without context; in this study, communication is evaluated based on the objective of the communication, which is to solve a task where conversations are necessary to gather information for the task. When they exchanged enough required information with the virtual human, they would be told by the platform that the task is completed, and they are free to close the platform. Finally, they were asked to 3) fill out a post-visit survey. The entire study would take about 30-45 minutes.

Study Measure: this study used five post-exposure study measures for students to evaluate *iVisit-Communicate* from the following aspects: system usability, sense-of-presence, social presence, communication skills practice, and task load.

The system usability aspect was adapted from the System Usability Scale (SUS), which measures the ease of use, satisfaction, effectiveness, and efficiency of system design (Brooke 1996). It measures the system usability using ten statements on a 5-point Likert scale where one indicates strongly disagree and five means strongly agree. The SUS score can be calculated and normalized to a score ranging from 0 to 100 (Brooke 1996), where 68 is the approximate average score in the scale (Bangor et al. 2009).

The sense-of-presence aspect referred to students' sense of being on the construction jobsites in terms of realism and was measure using five statements on a 5-point Likert scale (Slater et al. 1994; Usoh et al. 2000). To compute the presence score, responses were aggregated (bounded between the min:5 and the max:25 points) and normalized from a 0 to 100 range (Eiris et al. 2020).

The social presence aspect was adapted from Harms and Biocca (2004), which measures the extent to which students would have the feeling of being with the virtual human. It was found that a virtual world with a high feeling of social presence may increase the communication quality as it connects students with the virtual human and create social interactions (Bulu 2012). It measures the social presence using twelve statements on a 5-point Likert scale where one indicates strongly disagree and five means strongly agree. Similarly, the total score was aggregated and normalized from a 0 to 100 range.

The communication skills practice aspect was adapted from the STEM (Science, Technology, Engineering, and Math) Interpersonal Communication Skills Assessment Battery (Wilkins et al. 2015). This battery was designed to measure an array of communication subskills, including active listening, assertive self-expression and receiving and responding to feedback (Rubin and Martin 1994). In this study, 20 psychometric properties of interpersonal communication knowledge assessment were adapted for students to subjectively assess if *iVist-Communicate* had provided them an opportunity to apply their interpersonal communication knowledge and practice their communication skills. The survey was presented to students using a 5-point Likert scale that contained 20 questions scaled from strongly disagree to strongly agree. The total score was calculated by adding the question scores and resulted in a range from 0 to 100.

The task load aspect was adapted from the NASA task load index to measure the subjective mental workload of performing a task (Agency for Healthcare Research and Quality n.d.). Six 5-point-Likert-scale questions were included to understand student's subjective workload to

perform the designed task in the two-way communication scenario. Similarly, the total score was aggregated and normalized from a 0 to 100 range.

Results and Discussion: twenty-five students participated in the experiment and left records on the *Qualtrics* platform. After cross-checked with the chat data history collected on the Google cloud database, only fourteen recorded were confirmed completed. The rest eleven records were excluded from the analysis as there were no collected conversational data that confirmed their participation in the iVisit-Communication platform.

For the fourteen students who completed the whole experiment (ten male and four female), their academic backgrounds were relatively evenly distributed, with four in the first year in college (28.57%), four in the fourth year (28.57%), one in the third year (14.29%) and one in the fifth year (14.29%), and four graduate students (28.57%). Most of the students majored in construction management (35.71%), civil engineering (28.57%), and architecture (21.42%). Most of them had none (46.15%) or little (30.77%) working experience. Overall, participants had some knowledge of HVAC and plumbing systems and had fair knowledge about 360-degree panoramic images and Virtual Reality.

Table 1. Descriptive Statistics for Study Measures

Study Measure	Quantitative Variable			
	Mean (%)	Standard Deviation (STD) (%)	Maximum (%)	Minimum (%)
System usability	63.39	16.77	85.00	35.00
Sense-of-presence	55.15	23.35	93.33	20.00
Social presence	72.74	11.67	93.33	50.00
Communication skills practice	76.36	21.04	100.00	21.00
Task load	47.88	18.09	83.33	20.00

An analysis was performed using descriptive statistics (Table 1). Based on students' feedbacks from system usability aspect, an average usability score of 63.39 was obtained (STD = 16.77%; Max = 85.00%; Min = 35.00%). It was slightly lower than 68, which is the benchmark for average system performance. The major issue reported by students was that '*The (iVisit-Communicate) application shut down several times*', and similar comments were also found from students who didn't complete the *iVisit-Communicate* site visit experience. Furthermore, the primary researcher received seven emails reporting the same issue on students' computers. It was found that the *iVisit-Communicate* platform consumes a significant amount of the computer RAM (random-access memory) and may not be able to run smoothly or properly on computers with limited RAM (e.g., 4GB or lower). This limitation negatively affected the usability score of the *iVisit-Communicate*.

Students reported an average sense-of-presence score of 55.15% (STD = 23.35%; Max = 93.33%; Min = 20.00%), which indicated a moderate level of realism and immersion during the virtual site visit. It was found that students were able to '*develop a strong sense-of-presence*' when the program flowed flawlessly; however, the sense was severely reduced '*when the program experienced lag*'. The lagging issue might be explained by the limited rendering capability or RAM of the computer. Additionally, a student commented that adding relevant sounds, other workers or moving objects may improve the sense-of-presence of the experience.

Students reported an average social presence score of 72.74% (STD = 11.67%; Max = 93.33%; Min = 50.00%), which indicated students had a high level of feeling of being with the virtual human throughout the experience. Specifically, students reported that the virtual human's presence was obvious to them, easily caught their attention, and they were able to comprehend virtual human's narrative contents. Students' comments stated that the social presence might be improved by 'a proper voice actor' to convey emotions and help students pay attention.

The communication skills practice score revealed that most students somewhat agreed (Mean = 76.36%; STD = 21.04%; Max = 100.00%; Min = 21.00%) that *iVisit-Communicate* provided them the opportunity to practice their communication skills such as active listening, assertive self-expression and receiving and responding to feedback. The two-way communication process was also assessed objectively. On average, the communication process took students 10 minutes to finish the designed task, and 71% of the students achieved the goal of communication (i.e., solve the task).

The task load score revealed that most students found the task required a moderate level of workload to accomplish (Mean = 47.88%; STD = 18.09%; Max = 83.33%; Min = 20.00%). This indicated that most students felt this task was mentally, physically, and temporally demanding at a moderate level. They assessed their performance neutrally and suggested the accomplishment of the task took a moderate level of effort and caused a moderate level of frustration. This score suggested that the task was designed properly in terms of the workload demand.

CONCLUSION AND DISCUSSION

Communication is a critical skill for construction management students, and site visits can provide students a real-world context of construction jobsites where they can practice communication skills with the subject-matter-experts. However, site visits are not widely applied in the construction curriculum due to many challenges, including logistic limitations and geographical constraints. This paper proposed *iVisit-Communicate*, an interactive 360-degree site visit along with a conversational virtual human who guided the visit and acted as the subject-matter-expert. The processes of designing and developing *iVisit-Communicate* were introduced in detail, and a virtual site visit to a mechanical room was implemented as a case study.

This study assessed *iVisit-Communicate* from five aspects: system usability, sense-of-presence, social presence, communication skills practice, and task load. It was found that *iVisit-Communicate* was slightly below average from the system usability aspect (Mean = 55.15%; STD = 23.35%). This level of usability was mainly due to limited computer performance (e.g., limited RAM and graphical rendering power); therefore, it is essential for future study to completely control the hardware that is used for the study, or the developed platform needs to be widely tested on computers with various configurations to guarantee the same level of usability on different computers. This can also avoid lagging issues during the site visit and improve the sense-of-presence score (Mean = 55.15%; STD = 23.35%). Furthermore, students perceived a high level of social presence of the virtual human (Mean = 72.74%; STD = 11.67%) and suggested that employing a more natural voice that conveys emotions may further improve the social presence. The communication skills practice score (Mean = 76.36%; STD = 21.04%) indicated most students somewhat agreed that *iVisit-Communicate* provided them an opportunity to practice communication skills, and the task scenario for the two-way communication was designed properly that required a moderate level of workload (Mean = 47.88%; STD = 18.09%).

In this proof-of-concept study, the assessment was mainly based on subjective self-reported data; in further study where a more comprehensive understanding on *iVisit-communicate* has been established, it is expected to analyze the application using objective data to further contribute to the advancement of knowledge. Moreover, this study tested *iVisit-communicate* using a relatively small group of students, thus the generalization of the results must be made carefully, and tests for larger group sizes need to be conducted in future studies for further generalization of the results. Furthermore, in this study, the personal, affective, and other behavioral attributes are not the same in *iVisit-communicate* as with in-person communication. While *iVisit-communicate* provides a supplementary opportunity for students to practice communication in a construction-relevant scenario when such opportunity is not available in reality, it can not replace students' communication practice with real person in real life. Nevertheless, with the development of Virtual Reality, 3D character modeling and simulation, and the improvement of hardware (e.g., equipment with strong computing rendering power), *iVisit-communicate* may be improved with more personal, affective, and other behavioral attributes and support communication practices with better quality.

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