

Teaching Architectural Technology Knowledge Using Virtual Reality Technology

Enseigner les connaissances en technologie architecturale à travers la technologie de la réalité virtuelle

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Abstract

Construction detail (CD) knowledge is one of the leading learning components in architectural technology (AT) study. The traditional pedagogical method adopts a series of two-dimensional drawings to explain three-dimensional objects. The interactive and immersive features of virtual reality (VR) technology attract attention from the educational sector. While architectural design education has begun exploring integrating VR tools in the classroom, especially in the early design stage, AT is one of the very few subjects that have experimented with VR. This research, undertaken from within a larger, ongoing project, aimed to explore if VR could assist in teaching AT knowledge, especially CD. The project has two phases: phase 1 created several VR lessons that explained specific AT knowledge, using a VR technology currently available for educational purposes; phase 2 adopted a mixed method approach to investigate learners' experience with the VR lessons created. This paper focuses on the experience in building up a VR learning environment in phase 1. The initial findings after phase 1 showed that the VR technology adopted in this project was not a perfect tool in creating a VR experience in the CD field but could still offer students degrees of virtual reality learning experience.

Keywords: Virtual reality; Immersive learning environment; Architectural technology; Construction detail

Résumé

La connaissance des détails de construction (DC) est l'un des principaux éléments d'apprentissage dans l'étude de la technologie architecturale (TA). La méthode pédagogique traditionnelle adopte une série de dessins bidimensionnels pour expliquer les objets tridimensionnels. Les caractéristiques interactives et immersives de la technologie de la réalité virtuelle (RV) attirent l'attention du secteur de l'éducation. Alors que l'enseignement du design architectural a commencé à explorer l'intégration des outils de RV dans la salle de classe, en particulier au stade de la conception

initiale, la TA est l'une des très rares disciplines à avoir fait des expérimentations avec la RV. Cette recherche, entreprise dans le cadre d'un projet plus large et en cours, visait à explorer si la RV pouvait aider à enseigner les connaissances en matière de TA, en particulier le DC. Le projet comporte deux phases : la phase 1 consiste à créer plusieurs leçons de RV qui expliquent les connaissances spécifiques de TA, en utilisant une technologie de RV actuellement disponible à des fins éducatives ; la phase 2 consiste à adopter une approche de méthode mixte pour étudier l'expérience des apprenants avec les leçons de RV créées. Ce document se concentre sur l'expérience de la création d'un environnement d'apprentissage de RV dans la phase 1. Les premiers résultats après la phase 1 ont montré que la technologie de RV adoptée dans ce projet n'était pas un outil parfait pour créer une expérience de RV dans le domaine du DC mais qu'elle pouvait quand même offrir aux étudiants certains degrés d'expérience d'apprentissage de RV.

Mots-clés : Réalité virtuelle ; Environnement d'apprentissage immersif ; Technologie architecturale ; Détail de construction

Introduction

Virtual reality (VR) technology builds a computer-generated environment that immerses users in a simulated world to play and learn (Bardi, 2019). Virtual reality attracts attention from various spheres of daily life, from healthcare and architectural design to education (Waugh, 2017). Educators, especially in the higher education sector, are starting to enter this uncharted territory by piloting VR experiments to teach certain subjects. For example, VR can create a digitally replicated learning platform that enables students to experience the function of a water pressure system which is traditionally learned through a real-world scenario (Lewington, 2020). However, can VR assist in teaching architectural technology (AT)? The current pedagogy of applying traditional methods to teach complicated AT knowledge poses challenges to learners, specifically new students, in a college-learning environment (multiple sources, personal communication, 2012-2021). This research explored whether one VR technology—EON Reality—could assist in teaching AT in a college's architectural technician/technologist program.

Background Information

Project Context

As a result of architectural practice evolution, AT study generally includes subjects that cover a variety of topics, such as architectural design, building science, and architectural materials (Emmitt, 2013, p. xii).

Traditional Architectural Technology Pedagogy

The conventional and primary learning method in AT education is adopting a series of two-dimensional (2D) drawings to explain a three-dimensional (3D) object. The 2D materials comprise

floor plans, building elevations, building sections, construction details (CD), specifications, and perspectives to define a 3D asset. Learners study all 2D materials related to the 3D geometry, envision the 3D asset, and understand various aspects of this 3D object. These aspects include not only the forms of geometry, the shapes on different surfaces, and the spatial relationships among multiple edges (Ching, 2015), but also the technical characteristics of different materials that form the 3D object and various construction techniques.

Architectural Technology Knowledge

As proposed by Wienand (2013), architectural technology can be identified in the following expressions: “the components we accumulate into buildings; that process of accumulation also known as building; the understanding of how to put them together; how that building eventually functions” (p. 11). Wienand (2013) explained that AT’s core task is to “produce architectural details, essentially the design of joints” (p. 12). Wienand (2013) further elaborated several significant functions of these joints, such as fastening the structures together, tightening various components, controlling the possible movement of parts, and securing the intersection between the interior built environment and external conditions (p. 12).

Simple Configurations.

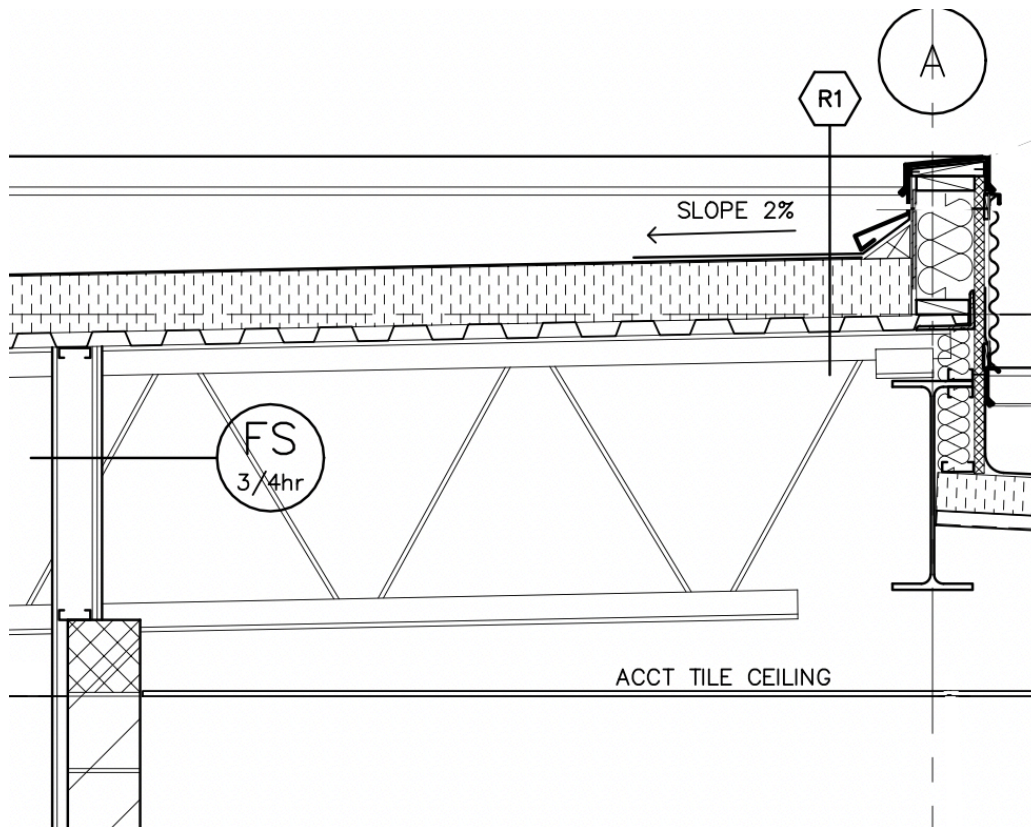
One of the principal learning components in AT is the CD drawing, which specifies a “realistic portrayal of what is to be assembled” (Page & Millar, 2021). One example is studying the composition of a steel roof assembly. This assembly consists of a steel beam, a portion of open web steel joist (OWSJ), a piece of steel deck, a layer of rigid insulation, a sheet of embramine, and a small number of ballasts (Figure 1).

The sole purpose of any drawing is to assist in communicating design ideas as precisely and concisely as possible to different audiences (Walshaw, 2021). Meanwhile, annotations that include technical writing and dimensions are indispensable components in any drawing. Besides sketching various building components for a roof structure composition, Figure 1 also incorporates a series of annotations offering technical information associated with the designed structure elements.

In architectural technology, Figure 1 is a 2D drawings that describes the concept: how a steel roof assembly is constructed. There are however other 2D drawings needed to fully explain the same assembly composition: plan view, elevation view, and CD of this roof assembly. These drawings work collectively to clearly illustrate one roof assembly.

Figure 1

The Detail of Standard Composition of a Steel Roof Assembly in AutoCAD Format



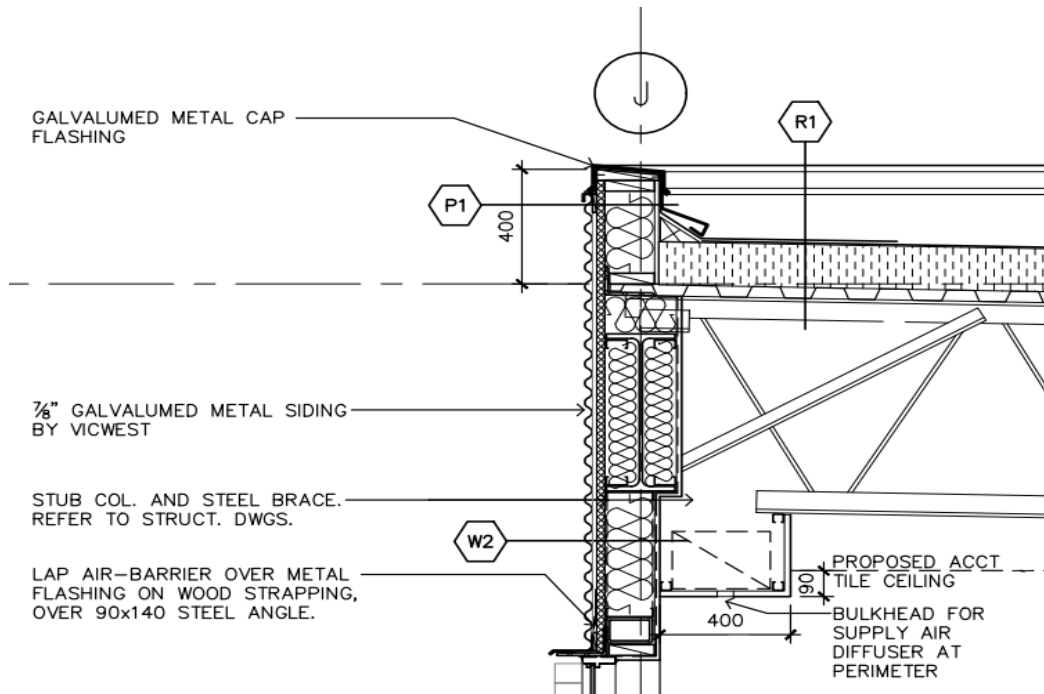
Note. This figure demonstrates the section view of a standard steel roof assembly that consists of multiple layers of materials. As shown in the illustration, the OWSJ is supported by the steel beam, and then the OWSJ supports the steel deck with a layer of rigid roof insulation and 2-ply modified bitumen roofing membrane on top. Together, these materials form the steel roof assembly. The detail symbol R1 indicates the steel roof assembly, with the rigid insulation on top of the steel deck (the rigid insulation is shown as a hatched pattern of broken vertical short lines). Adapted with permission from *Commercial/Industrial Building*, project number 15-002, drawing number A4.05, detail number 1, May 20, 2015, by F. Lapointe, Lapointe Architects.

Complicated Configurations.

Some CD drawings discuss even more complicated concepts. For example, the CD drawing that explains how two assemblies joint together to construct a new intersection is far more complex than the CD drawing that describes only one assembly composition. Figure 2 illustrates how two different assemblies, the roof assembly and the parapet assembly, joint at one point to create a connection near the rooftop.

Figure 2

The CD of a Steel Deck Roof Assembly Joists With a Steel Stud Wall Parapet in AutoCAD Format



Note. The image illustrates a steel deck roof assembly intersects with a steel stud wall parapet in its 2D drawing format, with correct composition of various building materials in the wall assembly and roof assembly. The detail symbol R1 indicates the steel roof assembly, detail symbol P1 represents the parapet wall assembly, and detail symbol W2 specifies the building wall assembly below the parapet. Adapted with permission from *Commercial/Industrial Building*, project number 15-002, drawing number A4.05, detail number 3, May 20, 2015, by F. Lapointe, Lapointe Architects.

Architectural Technology Learning Challenges

It is always challenging to elucidate a 3D object through traditional teaching methods. From a learning perspective, understanding the complicated compositions of various materials and visualizing the real-world assemblies or intersections among different assemblies through 2D methods always challenges students, especially new learners (multiple sources, personal communication, 2012-2021). Many architectural design programs have adopted advanced technologies to educate learners on various topics (Autodesk, n.d.-b). However, AT teaching remains a hard-to-reach area by modern innovations because of the complexity of its knowledge and numerous building materials and building science involved.

Theoretical Position

No architectural technology research project that explores adopting VR in teaching and learning could be found in current scholarly reports. Therefore, it was reasonable to seek inspiration from

academic fields closely related to AT. Building construction (BC), while separated from AT by superficial differences, has the same fundamental concept in learning as AT: studying a 3D object through a group of 2D drawings.

Literature Review in the Building Construction Field

In their comprehensive review regarding VR in BC education, Wang et al. (2018) discovered that developments on VR-related applications have been evolving constantly from old-school style to immersive and game-based VR technology. These advancements have benefited “architecture design, construction health and safety, equipment operation and structural analysis” (p. 12). On the other hand, Soliman et al. (2021) questioned certain market-available VR platforms because these technologies seemed to be developed primarily for “VR gaming and not education” use (p. 10).

Still, several groups of BC researchers around the world conducted experiments on applying different VR technologies to teach specific BC concepts. Although these experiments mainly focused on managing site conditions (Davidson et al., 2020; Hasanzadeh et al., 2020; Rahimian et al., 2020), some research projects explored how to construct particular building objects using VR innovation. Abdelhameed (2013) developed algorithms in XML code inside the VR Studio program and initiated a simulative function in an effort to assist learners in selecting the structural elements in the building design and structural design processes (p. 222–223). The VR simulation empowered students to imagine, specifically to study and understand, the 3D forms of the structural elements (p. 227). Meanwhile, Sampaio and Viana (2013) used the EON Studio VR system and 3D models to simulate the construction process steps of bridge decks (p. 2–3). Their research concluded that students could set the construction sequence based on the actual job site process and interact with the virtual models to study “in detail every component of the work and the equipment needed to support the construction process” (p. 5). Two years earlier, Martins and Sampaio (2011) created a simulative and interactive environment through programming software, EON Studio™, and 3D modeling applications, AutoCAD and 3Ds Max, to describe the launching sequence of a bridge and viaduct construction (p. 51-53). The virtual model illustrated the “complexity of geometry and materials concerning the different elements used in a real work process” (p. 55). In addition, this experiment elaborated a process of “how the different pieces of a construction element mesh with each other and become incorporated into the model” (p. 56). Similar to the previous experiment conducted by Martins and Sampaio in 2011, Bashabsheh et al. (2019) aimed to explain the steps of constructing a two-story house. They experimented using one VR technology, Unity game engine software, and a pair of Autodesk products, AutoCAD and 3ds Max, to create an immersive learning world (p. 716–717). Their project covered topics for the whole contraction process, from surveying the job site, representing stone and masonry works, to detailing the finishing and furnishing (p. 719–720).

Virtual Reality Benefits in Building Construction Learning

Learning materials created in VR are interactive. This interactive method helps learners to visualize how structural elements are constructed and how they relate to one another, thus reducing the confusion caused by the typical 2D-drawing learning format. For example, the interactive annotations

in the VR experience connect associated technical knowledge and prompt the learners' responses simultaneously (Abdelhameed, 2013, p. 222; Sampaio & Viana, 2013, p. 3). The users in Abdelhameed's (2013) research confirmed that they "had more clarity on the connections and spatial relationships of the structural system elements while using the VR environment" (p. 226). Moreover, Sampaio and Viana (2013) revealed that learners could interact with virtual building details according to the real-world construction methods, and VR learning enabled the users to "interact in an intuitive manner with 3D space" (p. 4). In addition, Martins and Sampaio (2011) confirmed that to facilitate learning, VR could be integrated into learning material to "allow direct access to any stage of the constructive process" so that learners could navigate to "any point within the virtual scene" (p. 49).

Furthermore, VR lessons significantly improve learner-centered instructional design strategy and increase learning efficiency. Learning materials created through a VR environment meet one of the universal design of learning principles, in which learners are offered multiple means of representation (CAST, 2021). The teaching strategy that combines interactive VR experience and the traditional 2D drawings benefits learners with different learning preferences (University of Waterloo, 2021; VARK, 2021). Additionally, Bashabsheh et al. (2019) proved that VR learning enhanced the learning experience and student satisfaction in teaching building construction courses (p. 723). The researchers discovered that students were more "interested in moving from the traditional way of teaching to other and more efficient teaching methods" and concluded that VR technology was a "good solution to increase the enjoyment of learning" (p. 723).

Possible Solutions for Architectural Technology Education

Although the above-mentioned building construction experiments did not directly relate to AT and the number of such studies is scarce, the experiences learned through these research projects shed light on AT pedagogy. Architectural technology instructors could adopt VR as one of the instructional design strategies to teach specific knowledge.

Learners and instructors consider AT knowledge, especially CD, as the hard-to-understand concept (multiple sources, personal communication, 2012-2021). However, it is challenging to build an actual physical, real-world scale model from a teaching perspective to explain the knowledge and improve learning experience. Hence, a virtual illustration could be an option to save time, space, and cost.

Research Questions

Virtual reality technology enables users to interact with a virtual object in a virtual world while situating them inside a virtual 3D environment to experience the designed object (Bardi, 2019). Therefore, the research questions would be: Can AT, especially CD, be taught using VR? Would learners understand the concepts easier if they were in an interactive simulated environment?

Methods

Research Design

This research project aimed to adopt VR to teach AT knowledge, specifically the CD concepts. This research project has two phases. Phase 1 involves adopting one VR technology to create individual VR lessons that explain specific AT knowledge, such as building envelope assemblies. Phase 2 involves surveying and interviewing voluntary participants to examine their VR experience based on the VR lessons created in phase 1.

This report is about the working experience attained through phase 1.

Project Team at Phase 1

The team consisted of the author of this paper and a group of student research assistants (SRA) from the AT program. When joining this project, SRAs had completed the second-semester study, which discussed targeted AT knowledge, so they understood the specific AT knowledge that would be used to create the VR lessons. Student research assistants participated in this project voluntarily and were required to engage in weekly Microsoft Teams (MST) meeting discussions and submit periodical written reports.

Phase 1 occurred in the summer 2021 semester and lasted for four months. While all SRAs were full-time students in the AT program, many worked part-time, and some worked full-time outside of school simultaneously. As a result, some SRAs could not submit periodic reports on time or had to withdraw from the experiment.

Data Collection and Analysis in Phase 1

Data Collection

The breakthrough of this project came during the summer 2021 semester, and the data reported was collected during this period.

An online MST group was formed for this project to facilitate the project management, and several folders were created under this group to collect documents for various purposes; for instance, a folder was designated for submitting project progress, and another folder was used to host general announcements.

Phase 1 focused on using specific technical features provided by EON Reality to create certain short online VR learning experiments. The content of these short lessons focused on CD knowledge covered in the second semester AT program. Student research assistants were divided into several groups. Each group was responsible for designing one online trial lesson with specific CD knowledge; for instance, a group was assigned to create a lesson that showed a steel deck roof assembly.

Following each MST meeting, one SRA wrote down the meeting brief and posted it to the group's folders created explicitly for collecting the meeting memos. Every SRA was required to submit

bi-weekly progress files along with progressive technical drawing files, where they would write down their reflections about their EON learning experience, and subsequently submit various documents to corresponding folders under the MST group. The analytical data collected during this period included 17 primary folders which harboured a total of 78 progress reports and 170 specific drawing files.

Data Analysis

Data reported in each periodic report and opinions discussed during each weekly meeting were analyzed immediately after each occurrence. Subsequently, a modified action plan was designed, and a discussion about the possible new move was carried out in the following weekly MST meeting. Once clarified and agreed upon by the team, the new strategy would be implemented.

Examples shown in this paper were selected to represent some of the incidents encountered by the team.

Data to be Collected in Phase 2

In phase 2, a mixed methods approach will be implemented. Phase 2 aims to answer the second research question: to explore whether volunteer project participants understand the concepts easier in an interactive simulated VR environment.

A pre-intervention survey will be distributed to volunteer project participants in the same AT program but registered for another academic year. This survey will collect baseline information about AT learners' present learning experience in the architectural program, as well as whether they have VR experience in AT or other academic learning settings. A post-intervention survey will seek feedback from volunteer project participants about their EON-lesson learning experience.

A focus group interview of ten volunteer project participants will be conducted to collect comments about their VR experience. Together, all data collected through the mixed methods approach will be cross-examined.

Justification for Tool Selection

It is expected that this research project will demonstrate one way to save time and money and reduce complications by using existing technologies.

The Virtual Reality Adopted

A market-available VR technology—the EON Reality platform—was chosen based on both the literature review in the BC field and its versatile technical functionalities, such as thousands of pre-made 3D assets, as well as its robust technical support for different academic areas in creating VR lessons for educational use (EON Reality, n.d.-b). EON also allows clients to use their unique 3D assets on its online platform to create VR lessons that convey a tailored immersive learning experience (Lejerskar, 2020).

The 3D Model Creating Software

The core design idea of this research project was to adopt 3D applications in order to create targeted 3D models which were subsequently inserted into one VR technology to generate an immersive learning experience. Architectural technology course instructors have been teaching a 3D modeling software, Revit (Autodesk, n.d.-c), in the major 9-credit design course. Students learn to create architectural building models that include simple structural elements, such as steel beams and steel columns, in the Revit platform. Therefore, adopting an application already familiar to SRAs would decrease the learning curve in this project, and using existing 3D models that included the targeted knowledge concepts could speed up the process and save time in this experiment.

Phase 1 Findings

EON is a superior technology that helps educators create VR lessons in various subjects, with its robust annotations tools and assistance from its technical support team. However, our project team went through several learning curves when creating VR lessons and phase 1 lasted several months because of a variety of issues that could not have been anticipated.

Experimental Virtual Reality Lessons Created

The outputs in phase 1 were remarkable. A large pool of regular progress reports and online digital links to a series of VR lessons targeting specific AT knowledge proved that EON's VR technology offers numerous advantages. The user interface is intuitive, so it is easy to learn and create new content. No coding knowledge is required and various source file formats are accommodated; for example, *.rvt (this extension refers to a digital 3D drawing file created and saved in Autodesk's Revit platform) or *.skp (this extension refers to a digital 3D drawing model created and saved in the SketchUp software). Final products are conveniently accessible through different external media channels, like YouTube (Chesler, 2019; Richardson, 2015).

Issues Encountered

Although EON offers many VR technology advantages, our project team encountered several technical issues.

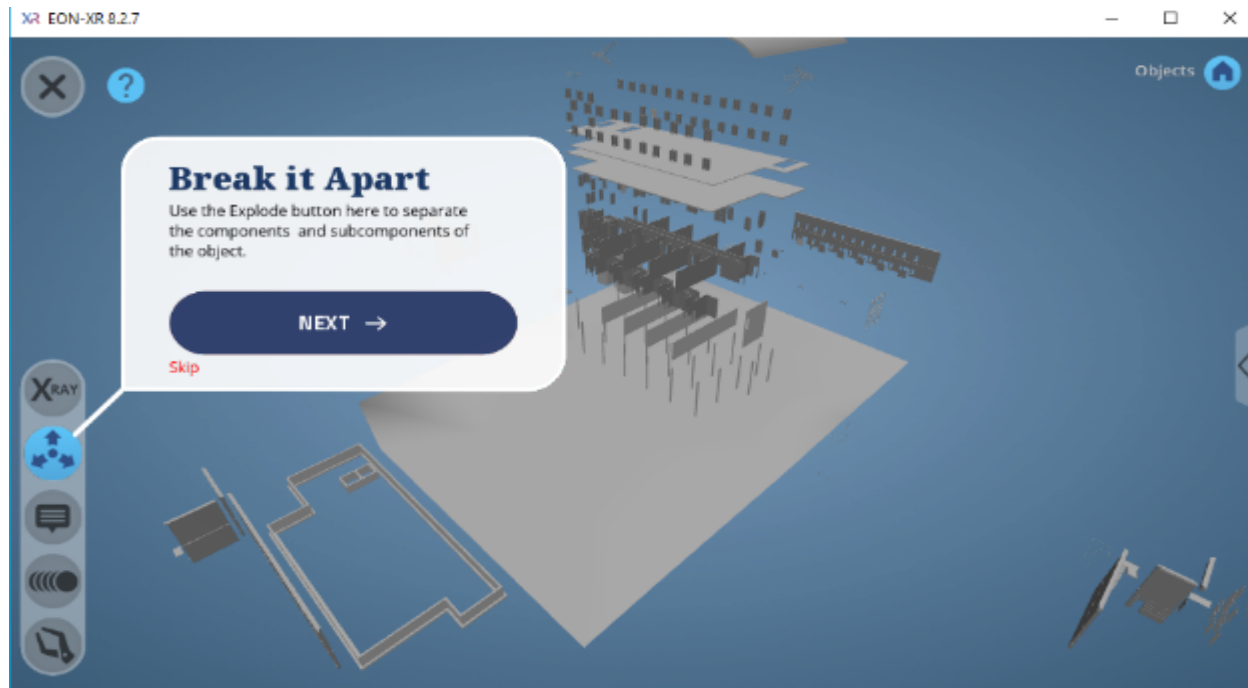
The First Try-Out

Following the procedure of this research, a previously created Revit model was used. The first try-out was converting the original Revit *.rvt file format into *.fbx (this extension refers to a 3D model saved in the Autodesk Filmbox format) file format that the EON platform could accept. After converting an existing Revit two-story commercial building project, the converted file was imported into the EON platform (Version 8.2.7). The team was amazed by EON's functionality accommodating such a complicated building model; however, it was disappointing that the original colours and material

textures on the Revit building model disappeared once the input was completed. Figures 3 and 4 show the model effects pre- and post-input.

Figure 3

The 3D Commercial Building Model in the EON Platform (Version 8.2.7)



Note. The inserted 3D Revit building model has only grey colour in the EON platform, and all building material textures were lost in the data importing procedure. The image, dated March 19, 2021, shows the effect after applying the Explode command. Every item in this model became grey and cannot be identified.

Figure 4 shows the same 3D model created in the Revit application before being imported into the EON application.

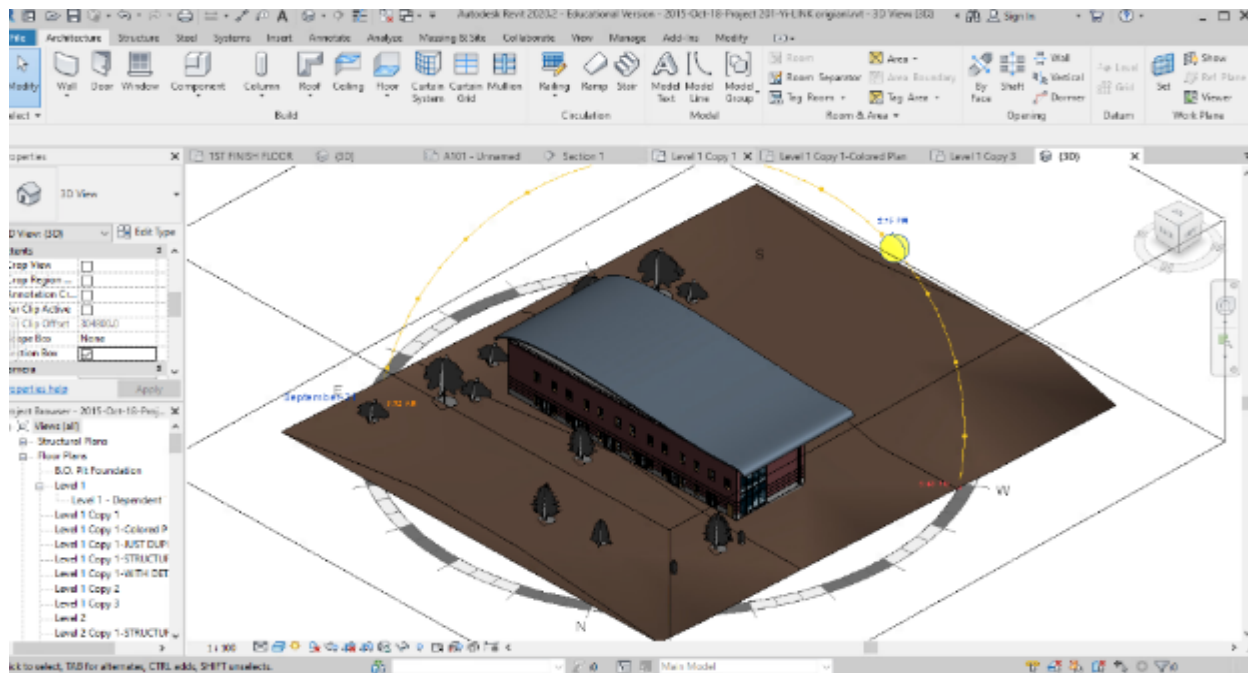
One of the many powerful functionalities of Revit software is its building information modeling (BIM) application that is typically used for “creating and managing data during the design, construction, and operations process” (Autodesk, n.d.-a). Users of Revit can choose from thousands of market-available BIM objects that have unique parametric data according to their own project needs and then construct their individual building models. For instance, engineers can select the correct type of steel joist BIM from one manufacturer that provides such a technological tool (Canam Buildings, 2021) and then insert this BIM to form part of the *.rvt structural model.

EON’s annotation function performs perfectly in line with Revit’s BIM data set. In our experiment, EON’s VR platform automatically identified each BIM object from the inserted *.fbx file that originated from the *.rvt file and displayed the name of each structural BIM element on the screen corresponding exactly to its sourced data. However, the 3D assets created in the Revit platform without

any generic BIM data could not be identified by EON's annotation function; as a result, manual data entry was required for each of these components. For instance, the curvy silver metal roof in Figure 4 could not be recognized because that was created in the Revit application manually as a generic 3D geometry.

Figure 4

The Same 3D Commercial Building Model in the Original Revit Platform (Version 2021)



Note. The original 3D Revit model has various colours for different building materials, and all material textures in the Revit application are legible. This is the same 3D model as shown in Figure 3 before importing to EON. Image dated March 19, 2021.

The Next Attempt

To explore if material colours and textures from the original 3D models could be maintained when importing to EON, the team experimented with SketchUp *.skp files. Adopting *.skp was a logical choice because: first, the *.skp files represent 3D models generated from the SketchUp software (Trimble, 2017); second, the *.skp file format is recognized by EON (EON Reality, 2020, p. 74); in addition, one of the AT courses taught the SketchUp application, so the project team was familiar with it.

In the experiment, *.skp files that concentrated on various CD knowledges were imported into the EON platform. The results showed that multiple colours could be seen and material textures could be detected. However, since models created from SketchUp ground were not parametric objects, EON's annotation function could not recognize any data, and thus, each annotation needed in the VR lesson had to be input manually.

The Following Try-Out

Understanding that *.skp files could produce excellent results in the EON program encouraged the team to create more useful 3D assets in the SketchUp platform. An online collection wonderland—3D Warehouse (<https://3dwarehouse.sketchup.com>) where manufacturers, designers, enthusiasts, and community members generate and share diverse SketchUp 3D modeling contents—had been discovered and explored. The search ended with inspiring and eye-opening results: a variety of 3D assets that related to CD were located and downloaded, for instance, the open web steel joist created by an individual (G., 2021) or a “floor ceiling steel-framed” model by a manufacturer (Georgia Pacific Gypsum, 2021). Using existing 3D models accelerated the progress of making 3D CD models for EON VR lesson creation.

The Subsequent Challenge

Useful assets from the 3D Warehouse could be directly imported into the SketchUp platform for advanced editing to match CD knowledge discussed in some AT courses. However, certain *.skp files downloaded from the 3D Warehouse could not be properly uploaded to EON (Lu, 2021a, p. 2). EON’s technical support team suggested there might be technical issues in those individual file structures and advised our team to download desired *.skp files and save as *.fbx, or *.dae (this extension refers to the digital asset exchange file) format (M. Kasica, personal communication, March 29, 2021). One of our SRAs discovered a simple solution to this format issue: saving the current 2021 version *.skp model backward to older versions of SketchUp, such as 2017 or 2018, and importing the older version *.skp file to EON (P. Villalba, personal communication, April 1, 2021). This method reduced the project’s overall time spent creating 3D models.

More Project Challenge

To prepare the prerequisites for the VR lessons, our team had successfully created several CD *.skp models. For instance, to create an asset that included a masonry wall assembly with a partial poured-concrete foundation in SketchUp, the team first selected existing assets from the 3D Warehouse website and then modified the model by adding components based on the CD knowledge discussed in AT courses. However, these newly created complicated files could not be successfully uploaded to the EON VR platform. Meanwhile, EON had been working on upgrades to a newer version—EON-XR (Version 9.0). It was unclear whether the upgrade process was associated with the file uploading process, but our issue persisted, and the team idled for two months and could not progress as planned (Lu, 2021b, p. 2).

The Biggest Hurdle

The biggest hurdle in working on this project at phase 1 was the ongoing advancement of VR technology. EON’s technical development was constantly evolving, and unfortunately, the advancement still could not fix some of the technical issues the project team encountered because of AT knowledge’s complexity. This section focuses on some new technological developments and associated problems.

Colours and Textures of Building Materials

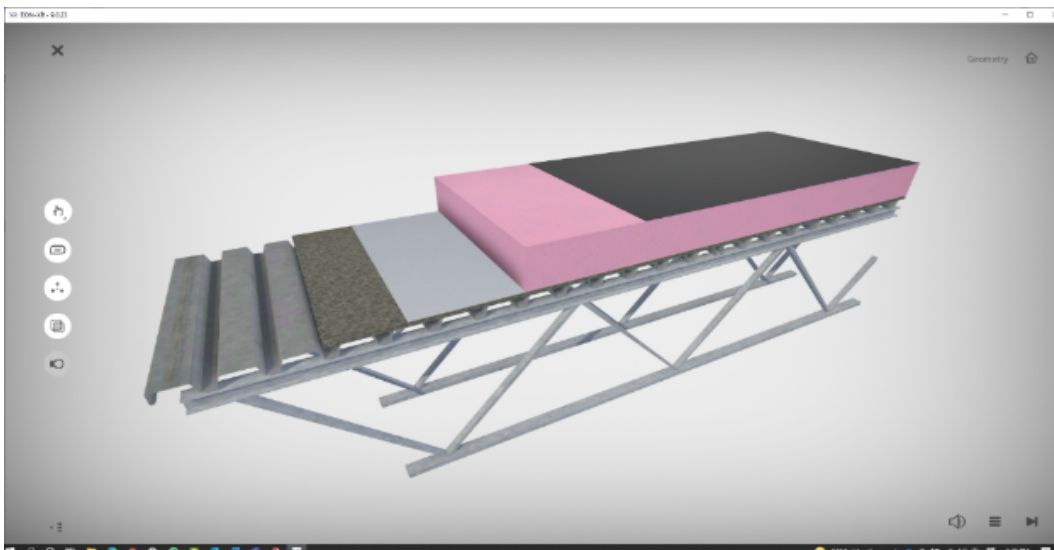
Our team created several VR lessons about specific CDs. However, there were still a few areas where the EON platform could not measure up to the rigor of AT due to the limitations of current VR technology even though the company continued to upgrade. For instance, the hatch colours and material textures on the original 3D model were still discoloured and unnatural after importing into the EON platform, despite using the *.skp file format and importing the model into the newer version of EON (Figures 5 and 6).

Explode Command

An issue persisted when using the explode command. As shown in Figure 7, this *.skp 3D model illustrates a steel deck roof assembly that usually contains stacked layers of materials in a specific order. After exploding this model in the VR platform, the components in the model were dispersed randomly with different orders and directions in space. Figure 8 demonstrates what happened when applying the explode function.

Figure 5

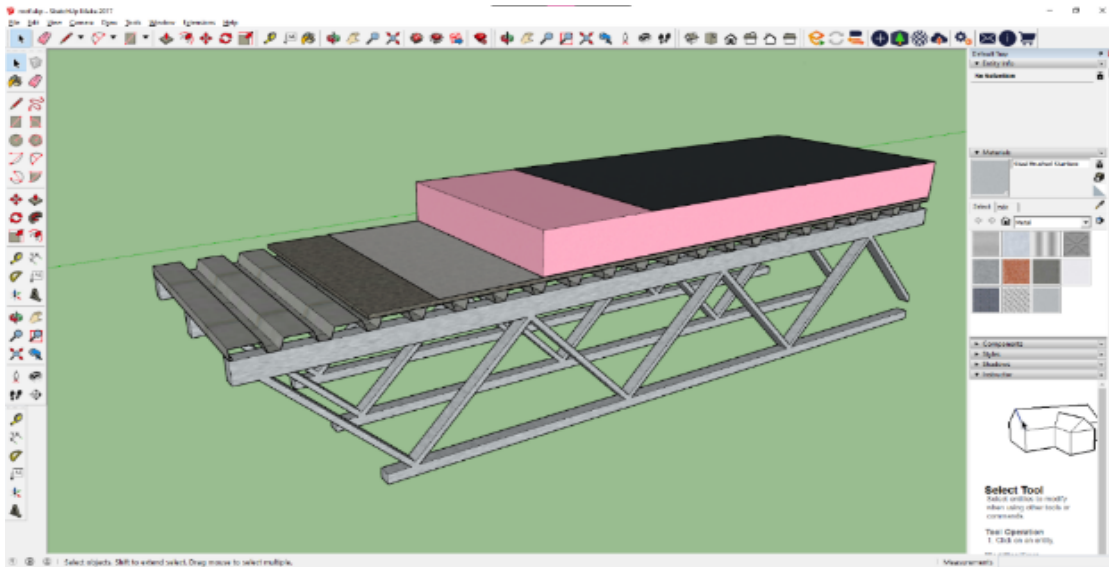
The Steel Deck Roof Assembly 3D CD Model in the EON Platform (Version 9.0.23)



Note. This figure presents the imported roof assembly *.skp model in EON. The effect shows discoloured materials and textures are lost after uploading the file to the EON application. Image dated July 5, 2021.

Figure 6

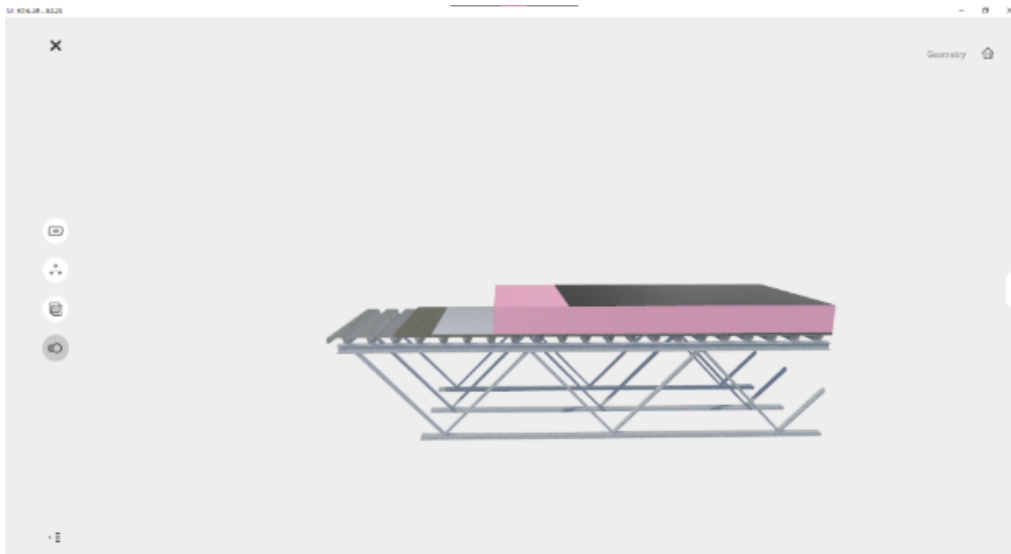
The Steel Deck Roof Assembly 3D CD Model in the SketchUp Platform (Version 2017)



Note. This figure illustrates the original 3D *.skp model in SketchUp that displays the precise colours and textures of various building components. This is the same 3D model shown in Figure 5 before importing to EON. Image dated July 5, 2021.

Figure 7

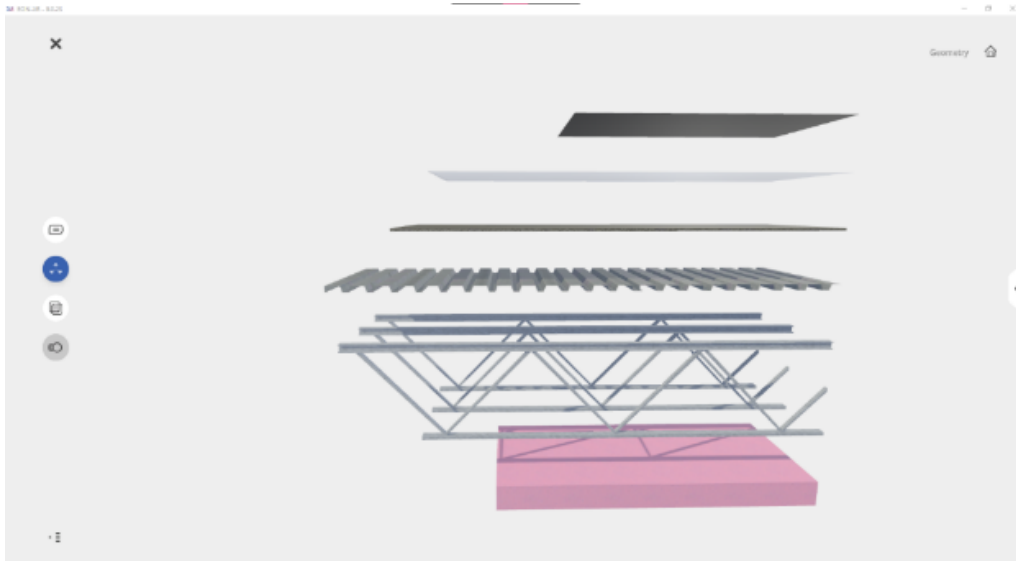
The Steel Deck Roof Assembly 3D CD Model in EON Platform (Version 9.0.23) Before Exploding



Note. This figure demonstrates the imported *.skp model in the EON platform. It maintains the correct order of layers of different building materials before applying the explode command. As shown, the OWSJ supports the steel deck, a layer of rigid insulation (in pink) sits on top of the steel deck, and a layer of the roof membrane is on the very top of this roof assembly. Image dated July 5, 2021.

Figure 8

The Steel Deck Roof Assembly 3D CD Model in EON Platform (Version 9.0.23) After Exploding



Note. This figure presents the effect of the imported *.skp model in the EON platform after applying the explode command. The image exhibits layers of different building materials with imprecise orders and orientations. For instance, the pink piece of rigid insulation is located under the OWSJ. In AT, the rigid insulation should be located on top of the steel deck in order to construct an effective building envelope. Image dated July 5, 2021.

To further explain why the order of building materials is essential in AT learning, let's review one 2D working drawing details that describes the steel deck roof assembly (Figure 9).

In architectural technology learning, the order of the layers of materials in any CD is critical. Building materials not only have their own compatibility with the climate and environment in which the building is located, but also the physical properties of each material and the specific composition of a group of materials impact code compliances and the building energy performance (Crisman, 2017). Figure 9 demonstrates the precise technical knowledge involved in studying a steel roof assembly CD.

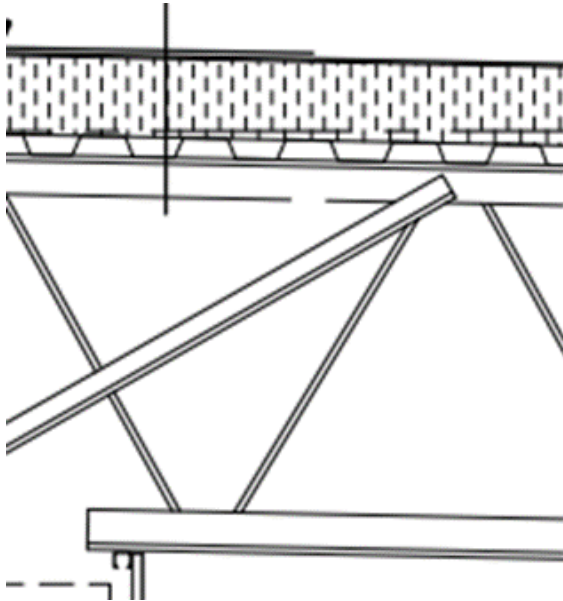
Similarly, Figure 7 shows the correct composition and order of the steel deck roof assembly before applying the explode command in the EON platform. The rigid insulation (the pink layer of material) is located under a sheet of roofing membrane to protect the building occupants from weather conditions outside the building. In comparison, in Figure 8, the rigid insulation has been mistakenly placed under other structural components, so the function of rigid insulation has strayed. As a result, incorrect learning occurs (Lu, 2021c, p. 5).

Annotation Function in Version 9.0

Other than the components being mislocated once the 3D assembly was disassembled, the tags for each element became mixed up and dispersed in different directions. The effect of this is shown in Figures 10 and 11.

Figure 9

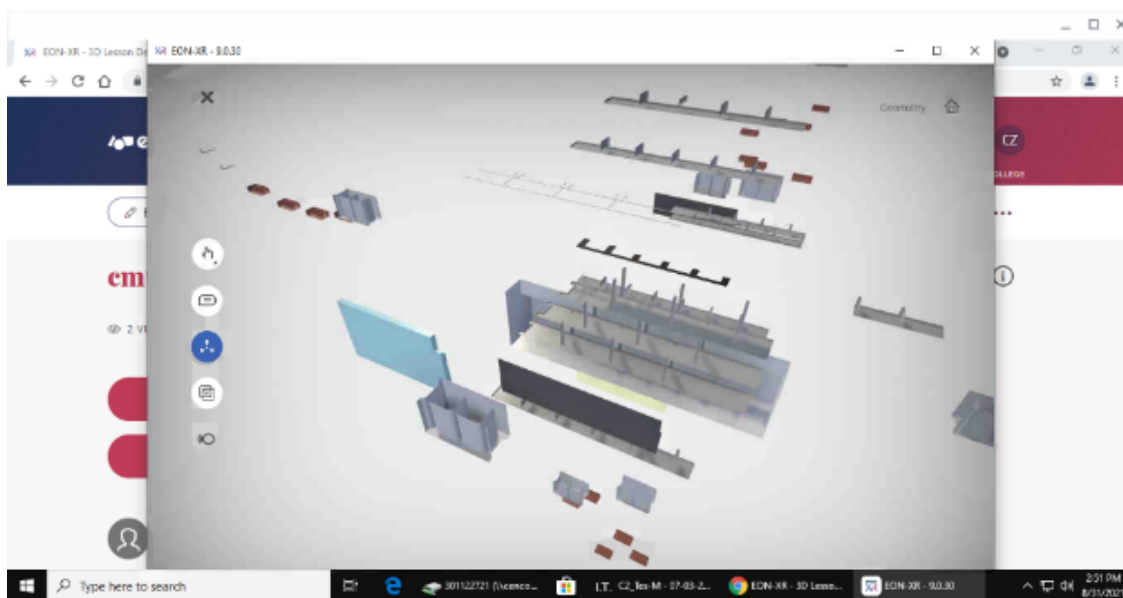
A Zoom-in View of the Steel Deck Roof Assembly CD in AutoCAD Format



Note. The image shows a steel deck roof assembly with the correct order of various roofing components. The drawing shows that the OWSJ supports a steel deck, and a layer of rigid insulation is on top of the steel deck; a final layer of roof membrane finishes the roof assembly. Adapted with permission from *Commercial/Industrial Building*, project number 15-002, drawing number A4.05, detail number 3, May 20, 2015, by F. Lapointe, Lapointe Architects.

Figure 10

The VR Lesson Shown in the Newest Version Before Enabling Annotation Function

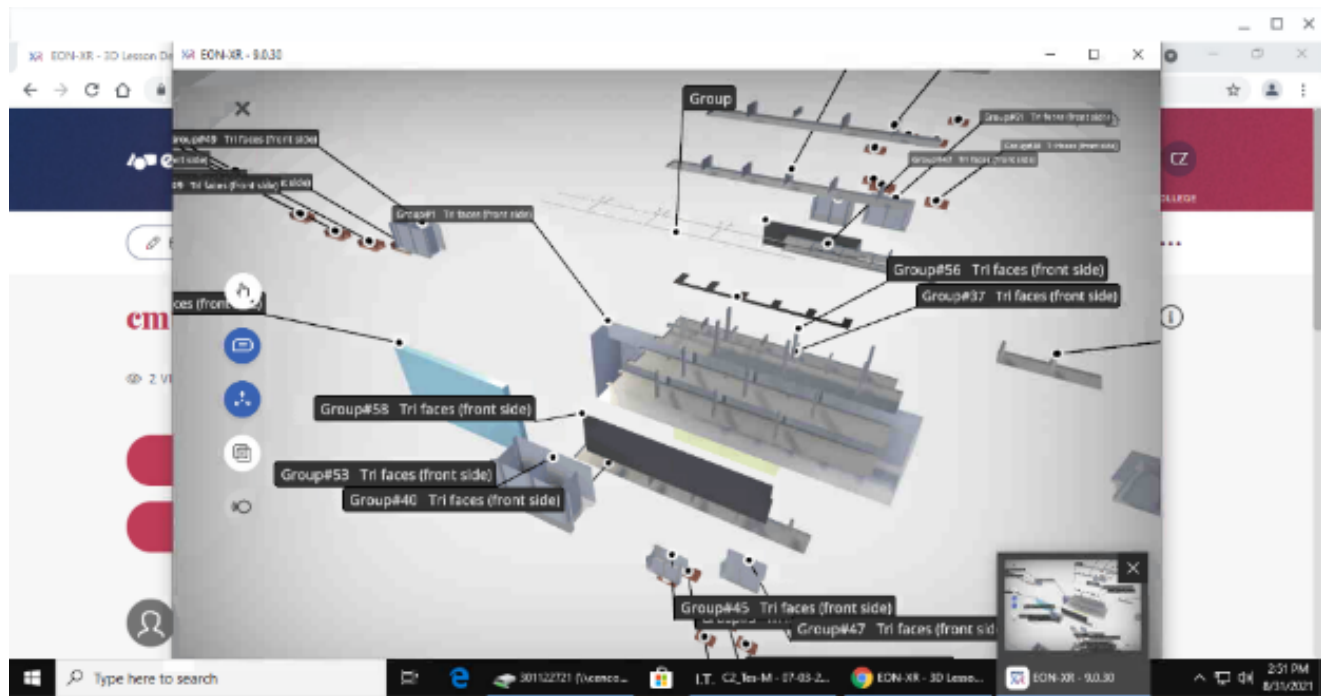


Note. This illustration shows how, before enabling the annotation function, various components dispersed from the brick on the concrete masonry unit wall 3D model after applying the explode command. Image dated August 30, 2021.

Figure 11 shows how various model components link with their own tag after the annotation function has been enabled. In AT's working drawing, as shown in Figure 2, the arrow of the annotation must point to the exact material that the text is referring to in order to make sure there is no misunderstanding or miscommunication among various building professionals, because all annotations in the CD, along with other technical information on the CD drawings, are the primary document used by construction site professionals from different trades (Kubba, 2017, Chapter 13).

Figure 11

The VR Lesson Shown in the Newest Version After Enabling Annotation Function



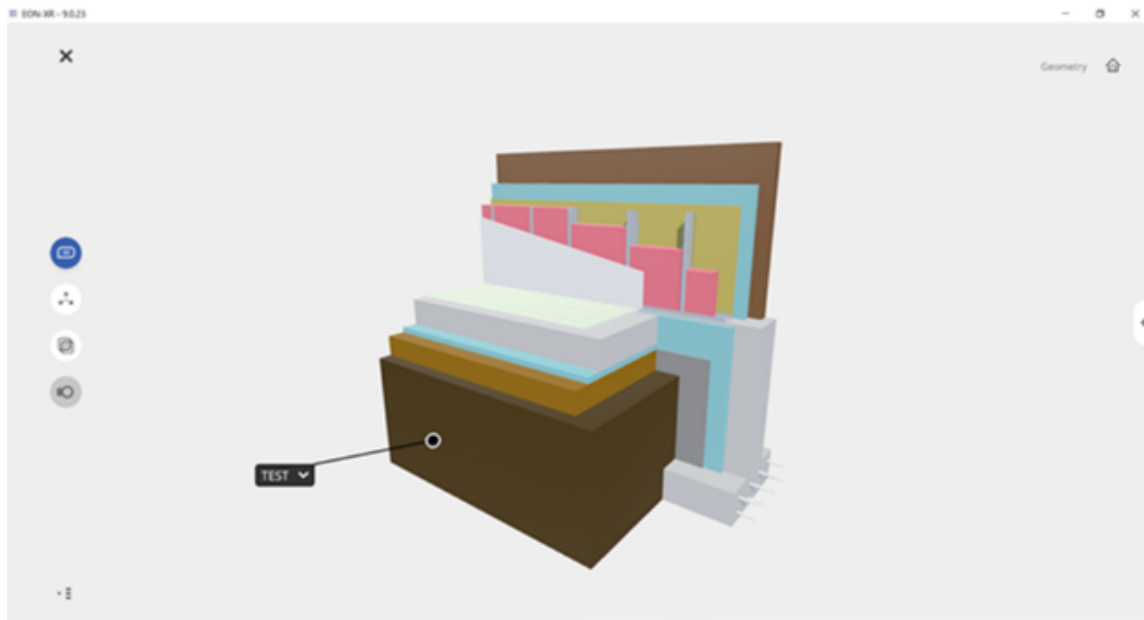
Note. This image exhibits how the tags for different components scattered from the brick on the concrete masonry unit wall 3D model after enabling the annotation function. The lines between text and corresponding components do not reach. Image dated August 30, 2021.

Annotation Function in Version 9.1

The newly released version—EON-XR (Version 9.1)—did not fix the rendering issue that occurred in the older version. Moreover, our team discovered a new problem: the annotations created in the older version vanished. Hence, the team had to re-create all annotations for each VR lesson. This issue is shown in Figures 12 and 13.

Figure 12

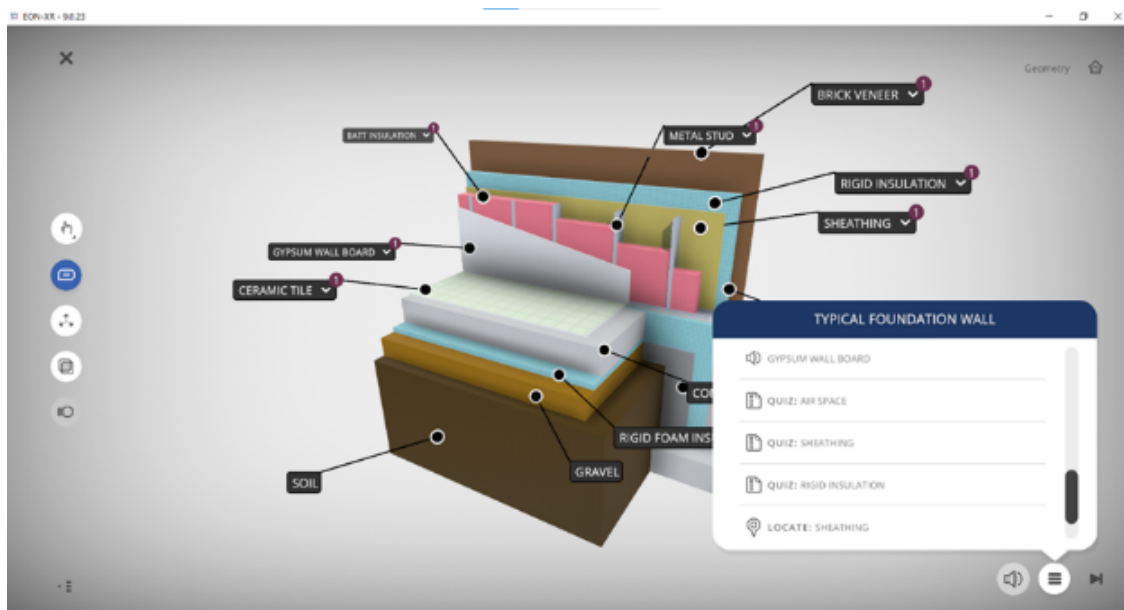
The VR Lesson Created in the Previous Version Displayed in the Newest Version



Note. The image shows how annotations vanish in the newest version. This VR lesson on wall assembly was created from the previous version. Image dated September 3, 2021.

Figure 13

The Re-Created Annotations in the Newest Version



Note. All annotations in this VR lesson, including tags, captions, quizzes, digital voicings, and so on, had to be re-created for the same model shown in Figure 12. Image dated September 3, 2021.

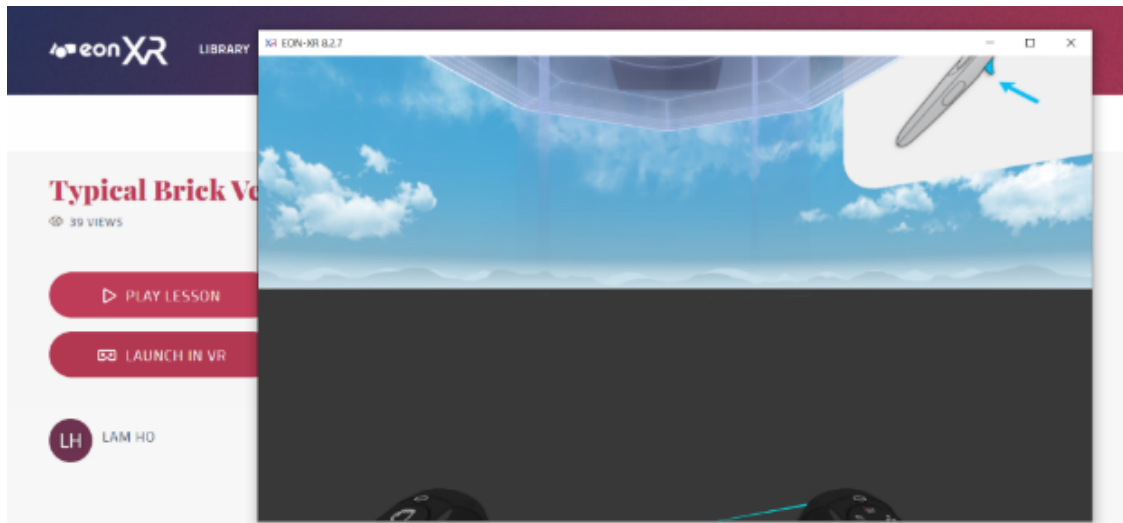
Other Technical Issue

The VR function was perfect when using a desktop in the older version, but this was dropped in the newest version; fortunately, VR function was maintained in the hand-held device format so users could still try out the VR experience on their cellphones.

Figure 14 shows that users can experience the VR function on a desktop computer without a headset, but this function was removed in the newest version of EON.

Figure 14

The VR View in the Older Version of EON (Version 8.2.7)



Note. The image shows one of the screenshots of the VR experience on a desktop computer without the headset. Image dated July 25, 2021.

Discussion

EON Reality is an excellent VR tool to create an interactive learning experience (Lejerskar, 2020). It enables the view and analysis of a 3D object from 360 degrees, both outside and inside, and accepts models created by various applications (EON Reality, 2020, p. 74), accommodating the lesson creator's capability and available resources. EON's annotation function is superb in recognizing BIM data embedded with a 3D asset. For example, in the case of a 3D model built up in the architectural professional software Revit, the data associated with its BIM elements can be picked up by EON's annotation function when making a VR lesson. This function can pinpoint the exact model components linked with BIM parameters and showcase the data automatically and precisely. This feature eliminates the time needed to input all the tags and reduces the possibility of making mistakes when data is entered manually. It significantly speeds up the whole VR lesson creation process and ensures information accuracy.

Even though the project team encountered various barriers when creating VR lessons, the experience gained throughout the phase 1 process was valuable in studying targeted AT knowledge and improving teaching strategies (Lu, 2021c, p. 11). Student research assistants stated in weekly project meetings that working on these VR lessons benefited their own understanding of certain CD concepts, broadened their horizons on specific VR and other emerging technologies, and boosted their competitiveness in the job market (multiple sources, personal communication, July-August 2021). Virtual reality lessons enable users to virtually view the complex AT learning elements and understand the intricate spatial relationships among various components. While 2D drawings certainly are a precise approach to showing technical information, VR can transform the teaching to be more engaging and easy-to-understand.

Conclusion

The Project

Phase 1 of this VR project explored adopting a market-available VR technology to create specific lessons to enable learning certain AT concepts. Although it was not fully completed as per the project schedule due to a combination of factors: the EON platform's ongoing technical development and the funding for this project being for only one calendar year. Phase 2 is currently underway; in this phase, voluntary participants are testing the VR lessons and providing feedback about their VR experience. A mixed method approach will be implemented to investigate participants' quantitative and qualitative responses.

The Virtual Reality Tool

Even though EON Reality is upgrading constantly, its newest version still cannot correctly illustrate particular AT information. In AT, especially in CD study, the order and orientation of different structural and building materials are critical knowledge that does not allow for errors because it involves building science and energy efficiency requirements in building codes. Phase 1 would have achieved more remarkable results if the project could have lasted longer or waited until VR technology advanced to a level that meets the rigor of AT.

Phase 1 of this project confirms that VR technology benefits the learning process. The degree of such benefits depends on the rigor of the knowledge to be represented. It may be true that EON's VR technology works very well in teaching learning concepts in other academic disciplines (EON Reality, n.d.-a); however, its current technological advancement does not meet the standard of AT knowledge. Although the VR lessons created on certain AT concepts provide an interactive and immersive learning environment, VR cannot fully and accurately represent several specific AT topics.

Recommendations

The VR experience in phase 1 suggests that teaching professionals should work closely with technology developers to find solutions as some technological improvements were achieved when our team communicated directly with the VR development technicians. Moreover, the phase 1 study has indicated that the partnership between the application users and the VR technical team is ongoing and evolving. The educators continue taking the training courses provided by the VR platform to improve their VR lesson-building skills. The VR lesson creators should also immediately report any technical problems that emerge while creating the simulative experiences. Furthermore, this study suggests that either the researchers in the AT discipline should find another VR tool for their specific needs, or the current employed VR tool must advance to meet the rigor of AT knowledge. Therefore, more explorations on adopting VR in teaching AT learning should be conducted to advance this field of study.

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