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A BIM-BASED EDUCATIONAL GAMING PROTOTYPE FOR UNDERGRADUATE RESEARCH AND EDUCATION IN DESIGN FOR SUSTAINABLE AGING

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ABSTRACT

This paper discusses an educational gaming prototype developed with building information modeling (BIM) inputs that aims to facilitate undergraduate education and research in the subject of design for sustainable aging. Motivated by the steadily growing market demands for senior housing in conjunction of academic goals in graphical communication and building codes education, experiments have been conducted in an undergraduate construction management curriculum seeking for innovative pedagogical approaches. The integration of BIM and game engine creates a meaningful learning environment and research framework that features with enriched visualization and interaction wherein students can explore design criteria and code compliance requirements of senior-friendly housing design via task-driven gaming simulation. This paper introduces the theoretic framework, the design approach, and the developed prototype with use case demonstrations. Initial assessment and user feedback are discussed for further improvement on the developed prototype.

1 INTRODUCTION

It is a common practice today to integrate building information modeling (BIM) in college curricula of design, engineering and construction programs (Sabongi and Arch 2009; Becerik-Gerber, Ku, and Jazizadeh 2012; Wu and Issa 2014). Rapid adoption and implementation of BIM across the global industry justifies the need to educate future workforce on BIM principles and cultivate desired skill sets of BIM implementation. Various BIM pedagogical models have been experimented (Wu and Issa 2014) with focus on distinct topics catering to academic goals and program priorities. Noticeably, there is an emerging trend of converging the strengths of BIM and game engine to facilitate student learning in an educational gaming environment. This paper makes a similar effort by taking a unique perspective to examine design for sustainable aging facilitated by BIM and educational gaming.

The project is interested in assessing how visualization and interaction attained from the BIM-based educational game may enhance student understanding of design for aging principles and pertinent code compliance interpretation. Then entrepreneurial thinking is also incorporated to expand the project scope to a BIM-based educational game prototype development that aims to investigate practical solutions to improve design communication between design professionals and clients. The prototype serves as both a teaching tool and research framework for further inquiries on various use cases and scenarios relevant to sustainable aging.

2 BACKGROUND

2.1 Social and Architectural Implications of Design for Aging

Aging is a complex geographical process mediated by institutions and other social forces (Cutchin 2003). Housing plays an irreplaceable role in senior life. Human existence is closely related to architectural space, and results in individual patterns of spatial use (Lynch 1960). The interactions with architectural space, for instance, visualization and usage, supply meaning in the aging process (Cutchin 2003) Appropriate architectural design can also create supportive environments for the elderly (Devlin and Arneill 2003) and it has a therapeutic effect (Day, Carreon, and Stump 2000, Cutler 2007).

The home environment as a spatial expression has to be specially conceived for the elderly (Laws 1993). Design professionals embrace these ideologies and make conscious efforts in driving senior housing design towards aging in place. Considering the complex social context of aging in place and the natural connection between individual and community built environments, design professionals are urged to adopt a broad vision when interpreting the residential satisfaction of aging-in-place seniors. The study conducted by Rioux and Werner (2011) investigated personal and environmental predictors and identified a four-dimensional structure in elders' residential satisfaction corresponding to four distinct ecological areas: location, accessibility to services, neighborhood relationship and the physical home environment.

In an aging society, architecture and gerontology are two neighboring research fields that need to be explored in order to prepare for the senior citizens (Andersson 2011). Familiarization with the architectural space has been advocated as a component of successful aging in place (Grenier 2005). Research has been conducted on synergies between architectural design and gerontology (Brent 1999, Schwarz 1997) directing qualitative assessment of architectural quality and quantitative evaluation of accessibility and usability in architectural spaces. Design for aging is a national initiative that aims to accommodate the rapidly increasing senior population in the US, and to promote innovative design solutions that create the desired physical and service environments to facilitate sustainable aging process (Ball 2004, Wu and Handziuk 2013).

2.2 Architectural Visualization and Interaction in BIM and Educational Gaming

Architectural visualization is one of the early fields and low-hanging fruits of BIM implementation. In comparison with traditional paper-based approach and geometric modeling oriented CAD applications, BIM has a number of significant advantages attributed to the rich project information captured in addition to geometry, such as usability, materials properties, and the building process through the project's life cycle (Yan, Culp, and Graf 2011). The virtual reality constructed by BIM solutions provides the ideal context that clients can relate to their life experience and project expectations. It encourages active engagement of clients in the design process, which used to be an epic challenge in conventional architectural design for aging in place projects (Bullinger et al. 2010; Wu and Handziuk 2013).

In a typical cyclic architectural design process, current BIM solutions are able to serve designers' needs for better communication, coordination and conflict resolution. However, evaluating experiential aspects of the proposed design is an area that is still lagging behind (Balakrishnan and Kalisperis 2009). BIM lacks the behavioral information of its components that is needed to provide users with meaningful feedback when they try to interact with the design and act upon its elements (Kumar et al. 2011).

BIM will have to evolve toward a more user-centered, experience-based design, focusing on interactive spaces rather than focusing on digital representation (Heidari et al. 2014). It emphasizes user experience that reflects fundamental aging in place design criteria. These criteria attach significance to the quality of experience the elderly have when interacting with the design, and their psychological satisfaction through combined human computer interaction (HCI) with participatory design (Bullinger et al. 2010). Integrating immersive technologies and game engines with BIM can offer design professionals more than just the virtual mockup and digital representation. Clients can dive into the virtual environment to simulate experiential space interactions through self-guided or automated virtual walkthrough, perform interactive tasks and provide designers with meaningful real-time feedback on spatial quality, design comprehension and satisfaction (Bullinger et al. 2010, Yan, Culp, and Graf 2011).

Recently, BIM and game engine has also been broadly integrated in pedagogical innovations for learning enhancement and professional training purposes. For instance, Yang (2009) proposed a learning tool to educate non-experts about energy-related design and decision-making; Shen et al. (2012) developed a web-based 3D game project to demonstrate the process of using BIM to create an interactive 3D on-line training environment focusing on the energy commissioning; Rüppel and Schatz (2011) designed a BIM-based educational gaming approach for the exploration of the effect of building condition on human behavior during the evacuation process; Dib and Adamo-Villani (2014) described the development and initial evaluation of an educational game for learning sustainable building design principles and practices; Dawood et al. (2014) designed a 4D-based educational game for health and safety training in the construction industry; and Liu, Du, and Issa (2014a, 2014b) developed a framework to build a human behavior library through a BIM based cloud gaming environment and to solicit and collect human egress behavior data from a larger pool of human beings.

There is little, however, documented literature on BIM-based educational games for design for aging, or for the residential sector in general. This project acknowledges the significance of sustainable aging with both social and design connotations, and proposes to explore the leverage that BIM and educational gaming can potentially lend to promote education and research in this field.

3 RESEARCH OBJECTIVES AND METHOD

This overarching goal of this project is to create a BIM-based educational gaming prototype for the purpose of both teaching and research in the field of design for sustainable aging. To accomplish this goal, the following specific aims are pursued:

- Aim 1: Investigate factors that influence sustainable aging design iteration and effective design communication;
- Aim 2: Design and test a reliable workflow for integral information exchange between BIM and the chosen game engine with consideration for data format, processing and response time;
- Aim 3: Create the BIM-based gaming prototype that enables meaningful learning experience and supports robust user-design interaction scenarios tailored for sustainable aging projects; and
- Aim 4: Test the prototype using various uses cases and preliminary user data collection.

The project is initially integrated as part of an undergraduate construction graphics course to encourage students to investigate critical factors of design for aging through literature review and exploratory interviews with design professionals and local senior people. Students are then required to create conceptual senior-friendly designs using BIM authoring tools, incorporating their preliminary research findings. The BIM and game engine integration strategy, data exchange formats between the BIM application and game engine are reviewed and compared. The system architecture of the prototype is created with modular design concept taken into account, expecting to provide a generic framework for possible functionality expansion and use case development. The prototype is then tested with some simple educational/research use cases for user data collection and primitive assessment.

4 DEVELOP THE BIM-BASED EDUCATIONAL GAMING PROTOTYPE

4.1 Student Exploration of Sustainable Aging Criteria

Students identified multiple sets of design criteria at building and space level derived from aging in place design guidelines and regulatory documentation (e.g. ADA, ADADG and ANSI #A117.1). A brief market demand analysis was also performed by student groups through a series of interviews and surveys with local design professionals, senior citizens and senior housing investors. Based upon their findings, a generic time/effort mapping was created as shown in Figure 1 to define designer-user interaction and communication for decision-making on building planning and design, with descriptive design parameters and performance-based design outcome specifications. Essential iterations of designer-user interaction and communication in this mapping need to take place to make the design process truly integrated, considering that design professionals are fundamentally mediators between the architectural design and the inexperienced/non-expert users.

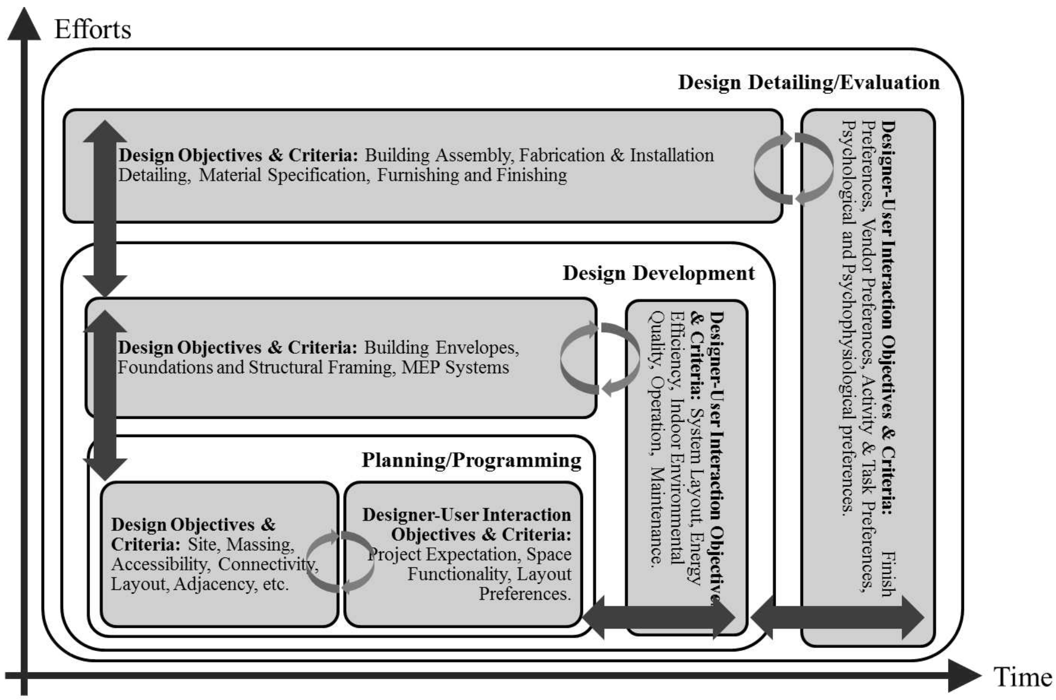

Figure 1: Time/efforts mapping for design criteria and design-user interaction.

The biggest obstacle perceived in current design-for-aging practices is the lack of effective design communication for clients to truly understand the design intention, considering that design delivery remains predominantly paper-based in the residential sector. On the other hand, designers seldom receive meaningful feedback from their clients so they could have modified the design to their expectation and satisfaction. Despite that some of the interviewed architects had already been using BIM, they found it challenging to clarify design intentions to clients and communicate with them in a way so all parties can reach real consensus. Another interesting discovery was that quite a few architects were providing clients with panorama renderings that could be reviewed in web browser to give a sense of interaction with the design. As little interaction as the panorama renderings could offer, most of these architects received very positive feedback from their clients, indicating better understanding of the intended design and material specification. Consequently, it is believed that the proposed solution based upon BIM-game engine integration could have the potential to significantly improve design communication and client satisfaction. Several local architects expressed interests in testing the prototype once it was developed.

4.2 Technology Selection and BIM/Game Engine Integration Strategy

From design authoring to game engine integration, various BIM and gaming platforms are involved. Factors that affect the selection of technology are multifaceted, as documented in the aforementioned literature. For design authoring, there is little competition due to the fact that Autodesk Revit has been the dominant BIM application in the North American market. Revit has a very intuitive user interface for beginners yet is powerful in terms of modeling capabilities. The constraint of Revit is its interoperability with mainstream game engines. Although Revit supports model export in various 3D file formats, it loses important information such as the relationship between model elements and their textures. The documented solution is to export a Revit model as a FBX file and edit the texture in 3ds Max, which is another Autodesk product. A common game engine such as Unity can read FBX directly, which makes it possible to edit the model components and see the results on the fly.

The most critical consideration in selecting game engines is the support of 3D asset import and cross-platform integration. Besides, user interface, graphical abilities including texture library and lighting effects, and animation editing are equally important. Unity is selected in this research due to the fact that it supports assets from nearly all major 3D applications like 3ds Max, Maya, Softimage, CINEMA 4D and Blender, to name a few. Unity is platform-neutral, and runs on Android, iOS and Windows Phone mobile devices. It also has the capabilities of development for PlayStation, Xbox360, Wii U and web browsers. The drawback of Unity, especially its free version, is lack of editing capabilities inside the game editor. It has no real modeling or building features other than a few primitive shapes so everything will need to be created in a third party 3D application, such as 3ds Max. Unity Pro, however, expands its features in global lighting and rendering-to-texture. Also, Unity offers an asset library where designers may download or purchase desired 3D assets created by content creators.

In summary, Autodesk Revit, Autodesk 3ds Max and Unity were selected to create the proposed prototype for the Windows platform. The development life cycle for the proposed prototype is illustrated in Figure 2. Student designs were authored in Autodesk Revit 2014, and exported as FBX files. The FBX files were further processed in Autodesk 3ds Max 2014 for material conversion and objects grouping to accomplish optimized graphical representation before imported into Unity as a new asset. Notice that an alternative approach that exporting the Revit model via Open Database Connectivity (ODBC) to a MySQL database, then reading model information from the database directly into Unity was tested as well. However, this approach proved to be problematic due to the loss of model element material property in transition from Revit to MySQL. Major scripting efforts took place after comprehensive interaction scenarios and functionality analysis, which dictated the animation scheme and graphical user interface design. After the prototype was created, use case demonstration and usability testing were conducted for user data collection.

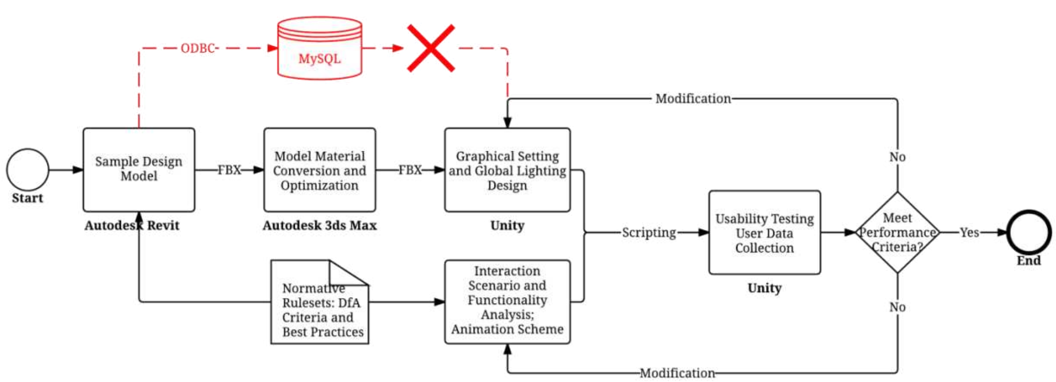

Figure 2: BIM-based educational game prototype development life cycle.

4.3 Prototype System Architecture and Gaming Logic

The prototype aims to establish a common framework that contextualizes user interaction with the design model in a gaming environment, with various deliberate interaction scenarios and functional modules through scripting. Its system architecture is illustrated in Figure 3. The essence of the system architecture design for the prototype is modularity. Information contained in the design model (BIM Database) is exported to the 3D Geometry Layer and Entity Attributes Layer to constitute the static scene of the game. Entity attributes will be loaded and assigned in runtime to corresponding geometry when a query is made. Avatars that represent different user profiles are stored in a dedicated library (Avatar Library), so are the scripts (Scripts Library).

The goal is to create an engine that supports user-centered interaction scenarios, e.g. varied perspectives among the elderly with distinct health conditions; and potential use of this game for design education. A gamer/user can decide to play a specific avatar to perform certain tasks by interacting with the Graphical User Interface (GUI) to act upon the 3D scenes and trigger the associated scripts, with the consequences/results being displayed as screen outputs.

As a generic framework, the prototype should provide the core functional modules through the Scenario Engine, and allows for fast Scene generation through the BIM Database export. However, there are circumstances when manual setups are needed to assign generic animation scripts to specific scene objects, for instance, identifying the door objects exported from the model and assigning the “swing” animation script to them. Also, at this stage, the GUI is designed for Windows PC desktop platform only, but the system architecture is applicable to web browser and other mobile gaming environments as well.

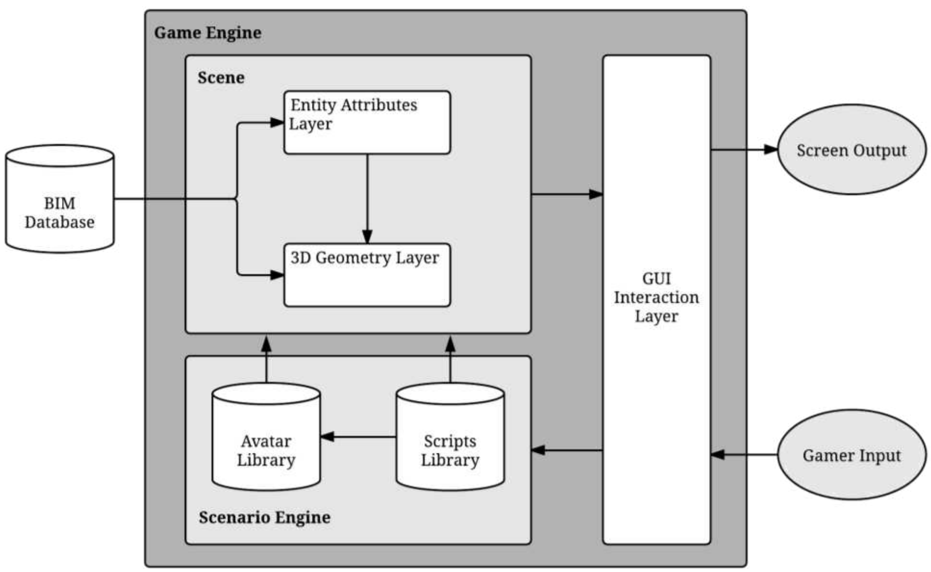

Figure 3: The system architecture of the BIM-based educational gaming prototype.

4.4 Prototype Graphical User Interface and Functionality

The proposed prototype is being developed and tested by the time of this paper. Simple interactions have been made available with a semi-completed graphical user interface (GUI) as displayed in Figure 4. Any scene object maintains the connectivity with its attributes inherited from the original building information model due the mapping between the 3D Geometry Layer and the Entity Attributes Layer. So when a building element is selected, its entity attributes will be displayed. Similar to typical game navigation, the Radar reports the real time locus of the avatar. The View Setting fine-tunes the gamer’s focal point and view range. The Defined Animation provides the gamer with a prescribed orientation walkthrough animation before the self-guided exploration. At this moment, the Defined Animation is hard-coded and does not support path customization. A path-finding algorithm has to be scripted to enable automatic path planning. Other features enabled for navigation include collision detection between the moving avatar and the bounding boxes of a fixed building element, e.g. the wall, and simple animations of movable building elements such as doors triggered by avatar traffic. A special navigation mode, Teleportation, is also enabled through the Functionality Tray.

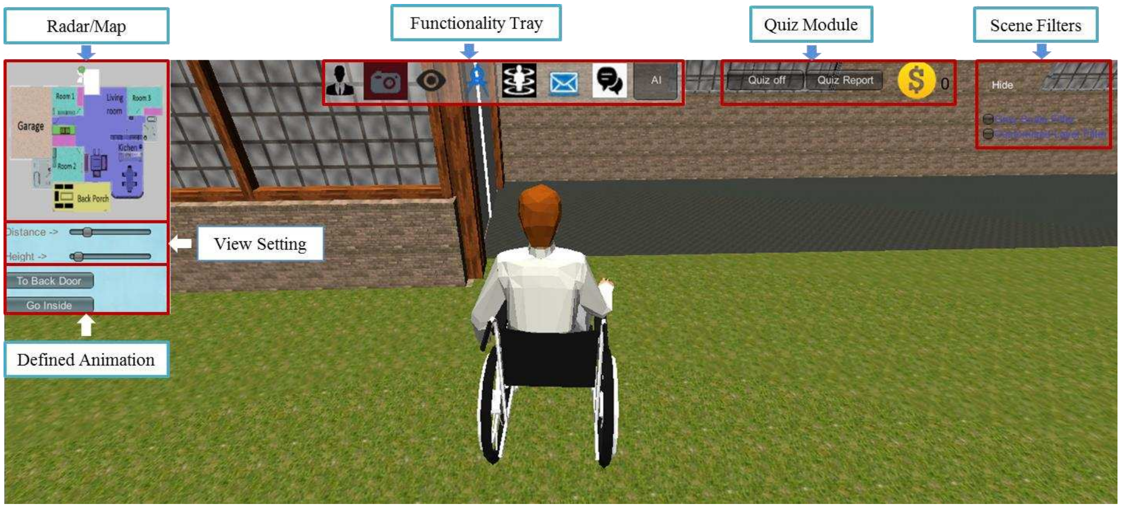

Figure 4: The graphical user interface of the proposed gaming prototype.

The Functionality Tray is the current focus of development. Table 1 provides a brief summary of its keys and intended functions. The Scene Filter is useful to highlight the focus of design at different stages, according to interviews with some local architects. For example, massing and space layout will be essential at the schematic design stage, which will be best represented with a grayscale, geometry-only game scene. In contrast, at detail design stage, it is more appropriate to use rendered, material-specific scene for design representation. So far two types of scene filters are provided: grayscale and element-based filters.

Table 1: Functionality Tray keys and intended functions.

Keys	Intended functions
	Avatar Selector: allows gamers to switch between multiple avatars
	Screenshot: allows gamers to create a screenshot and save it in a default folder
	First/Third Person View: allows gamers to toggle between first and third person views
	Measurement: allows gamers to measure distances in the model
	Teleportation: allows gamers to jump between place-marked locations
	Email: allows gamers to email collaborators
	Commenting: allows gamers to provide feedback on the game design
	AI: allows pathfinding/egress simulation in emergency evacuation

5 USE CASE DEMONSTRATION AND USER DATA COLLECTION

The developed gaming prototype will serve as both a teaching tool and research framework in the field of design for sustainable aging. With the prototype scenario engine being finalized, a senior-friendly design model can be exported and gamified inheriting the functionalities from the prototype, and enable gamer/user exploration. Various scenarios can be accomplished through further scripting with the developed prototype. The following paragraphs demonstrate two use cases using the gaming prototype for both education and research purposes.

5.1 Education Use Case: Quiz Module

The Quiz Module creates a sense of design education. Quiz dialogues (graphically represented a treasure box) are embedded and can be triggered with distance buffer controls at various locations where sustainable aging design criteria need to be considered. For instance, when the avatar navigates to the front entrance, a quiz will be activated once the avatar steps within the distance buffer. The gamer then can start a quiz that examines the gamer's knowledge of entrance and threshold design best practices and pertinent code requirements (Figure 5). The Quiz Module is useful in couple of different scenarios. It can help justify the design intention, and educate the elderly about essential features achieved through design deliberation to accommodate unique needs for physical/service environments of the senior life. The prototype can also be utilized as instructional instrument in college curricula and the quizzes will be a possible measure for assessment. Further experiment and fine tuning will be conducted in the upcoming semester when the prototype will be utilized in the undergraduate construction graphics course.

Figure 5: An example of the Quiz Module.

5.2 Research Use Case: Pathfinding/Egress Simulation

Pathfinding/egress simulation has become popular in emergency planning. This use case was developed in collaboration with the Computer Science department as a student research project on artificial intelligence in gaming development. The goal is to create and implement the "shortest path" to evacuate the avatar in a fire emergency using applicable pathfinding engines and navigation algorithms. The shortest distance problem is a sub problem of finding all paths between two points in a given terrain. This project takes into account three major areas where calculation of shortest distance is required: 1) pathfinding in Maze; 2) shortest path in a game; and 3) finding the nearest emergency exit in a building.

The Navigation system in Unity 3D facilitates creating characters or objects that can intelligently move in a virtual world. The navigation system uses navigation meshes (often termed as NavMesh, which indicates the walkable surface of the scene) to understand the environment (Figure 6). The A* algorithm is then applied to solve the shortest path. As one of the most popular pathfinding algorithms, A* combines the strengths of Dijkstra's algorithm and Greedy Best-First-Search to find a least-cost path (least travel time) from a given initial node to one goal node (Patel 2015).

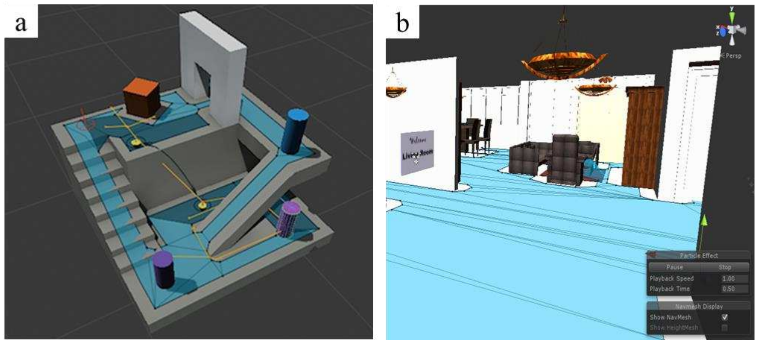

Figure 6: NavMesh detection in a) generic (Unity Technologies 2015); and b) the prototype.

The AI function in the developed prototype is the outcome of this exploratory research effort. When the gamer activates the AI command, a fire alarm will be triggered and the gamer will be prompted to set an evacuation destination outside of the building with mouse click. The shortest path for evacuation will then be automatically calculated and the avatar will start navigating to the destination (Figure 7).

Figure 7: Pathfinding simulation for emerging evacuation with the prototype.

5.3 Evaluation and User Data Collection

The prototype has been preliminarily demonstrated to construction, engineering, and interior design students, as well as local professional designers. It has also been packaged as a potential entrepreneurial idea submitted to a venture capital mini grant competition. Comments and feedback gained from these unstructured testing efforts confirmed its perceived value in design communication improvement and pedagogical implementation. Following common educational gaming design evaluation criteria such as indicated by Mayer (2012), a user feedback survey was conducted among a group of computer science capstone project students to attain preliminary gaming experience data that will be incorporated into further development and enhancement of the prototype.

The survey questionnaire consists of ten questions soliciting feedback on whether the developed prototype meets performance expectations on a set of critical factors of educational gaming design, including graphical user interface, quality of visualization, algorithm and design logic, functionality, cognitive loads and learning contextualization, to name a few. The evaluation is coded with a Likert scale of 1-5, with 1 being strongly disagree and 5 being strongly agree. The results are summarized in Table 2. More comprehensive educational gaming evaluation will be conducted via future course integration and prototype trials by professional designers.

Table 2: Results of user feedback survey on prototype gaming design.

Questions	Total Responses	Min Value	Max Value	Mean	Variance	Standard Deviation
The user interface of the game is easy to understand and navigate.	23	3.0	5.0	4.4	0.5	0.7
The graphics and visualization of the game are attractive.	22	3.0	5.0	4.1	0.5	0.7
The algorithm and design of the game are sound and meaningful.	22	3.0	5.0	4.1	0.5	0.7
The functionality of the game is sufficient and well integrated.	22	2.0	5.0	4.1	0.6	0.8
The content of the game is well reflected by design and functionality.	23	3.0	5.0	4.4	0.4	0.7
The game flows smoothly and is easy to follow.	23	3.0	5.0	4.2	0.6	0.8
The game enhances understanding of the subjects it aimed to address.	22	2.0	5.0	4.0	0.8	0.9
The game could enhance learning outcomes on the subjects in comparison with conventional lecture-based approach.	23	3.0	5.0	4.2	0.7	0.8
The game is technically easy and overall interesting to play.	22	3.0	5.0	4.2	0.4	0.7
I would like to use this prototype frequently if I had to learn the subjects embedded in the game.	23	3.0	5.0	4.0	0.6	0.7

6 CONCLUDING REMARKS

There are strong evidences that BIM and educational gaming integration is transforming professional practices as well as pedagogical approaches in the design, construction and engineering disciplines. This research examined opportunities of leveraging this new trend in the design for sustainable aging field. The urgency to accommodate an ever-increasing senior population and their housing needs will inspire professionals to embrace this brand new and innovative approach. This study addressed both academic and industry needs for better solutions to enhance understanding the practice of design for aging, and improve design communication and outcomes in real world project delivery. Built upon an undergraduate construction graphics course project with incorporation of engineering entrepreneurial mindsets, a BIM-based educational gaming prototype was created to provide an educational and research framework that transforms a static design model into a dynamic and interactive gaming environment, where user-centered and experiential communication between designers and clients would take place. A proof of concept was showcased to give an overview of the GUI and intended functionality of the prototype. Educational and research use cases were discussed to delineate potential implementation of the prototype.

The main challenge remains to be the data exchange between BIM applications and game engines. Current best practices suggest an indirect solution that requires extra time and resources. New information exchange open standards such as the Industry Foundation Classes (IFCs) may hold promise to streamline this process, and will be explored in future research. As mobile computing devices being widely adopted in both professional workplace and higher education, the gaming environment of the proposed prototype will be adapted accordingly. Efforts are devoted to investigating effective means for data communication between BIM and game engine in the cloud environment.

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