



Design for Aging with BIM and Game Engine Integration

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Design for Aging with Building Information Modeling and Game Engine Integration

Abstract

The senior population in the U.S. is growing steadily. Market research has shown that the majority of seniors would like to age independently in their own residence. However, the challenge to age in place is to create the physical and service environment that is resilient to accommodate the needs of seniors that are uniquely associated with the aging process. Design for aging is a professional practice dedicated to address this specific problem. As Building Information Modeling (BIM) is gaining industry-wide acceptance, its implementation in the residential sector is relatively limited. This study summarizes the experience and lessons learned from a project that is directed to explore the use of BIM and game engine to facilitate design for aging. The project is interested in assessing how visualization and interaction achieved via the integration of BIM and game engine may enhance student understanding of aging in place design criteria and pertinent code compliance interpretation. Then entrepreneurial thinking is also incorporated to expand the project scope to a BIM/game engine prototype development that aims to provide practical solutions improve design communication between professionals and clients. The paper shares the initial findings and showcases the prototype under development.

Introduction

Rapid adoption and implementation of Building Information Modeling (BIM) in the construction industry urges colleges to adopt this emerging trend and integrate BIM education in their curricula. Literature^[1] has shown that various pedagogical models have been introduced at different levels of commitment in design, construction and engineering programs across the country. This study contributes to the body of knowledge by addressing BIM implementation in a special niche of the residential sector, which is fairly overlooked when it comes to BIM transformation. 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^[2, 3].

Ideally, BIM empowers designers to accomplish this goal by introducing a virtual environment that facilitates rapid prototyping and design visualization. Nevertheless, a generic building information model 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^[4]. A game engine such as Unity, on the other hand, can engage users and encourage them to “play” with the model components, make purposeful interactions, and receive feedback in situ. The gaming experience can also be programmed to allow the participants to perform certain tasks and experiments that may yield significant insights into the functional features of the design that are impossible to attain with the generic BIM environment.

Situated in the context of college BIM education, this study is interested in how the integrated BIM-game engine solution will enhance students’ understanding of design for aging principles and pertinent code compliance requirements. Additionally, from the engineering entrepreneurship perspective, this solution bears business potential of serving the design for aging community. Initiated as a student project in an upper-division Construction Management (CM) elective course, extra efforts are devoted later to developing a prototype for enhancing communication between designers and clients.

Social/architectural implications of design for aging

Aging is a complex geographical process mediated by institutions and other social forces^[5]. Housing plays an irreplaceable role in senior life. Human existence is closely related to architectural space, and results in individual patterns of spatial use^[6]. The interactions with architectural space, for instance, visualization and usage, supply meaning in the aging process^[5]. Appropriate architectural design can also create supportive environments for the elderly^[7] and it has a therapeutic effect^[8, 9]. The home environment as a spatial expression has to be specially conceived for the elderly^[10]. 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^[11] 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^[12]. Familiarization with the architectural space has been advocated as a component of successful aging in place^[13]. Research has been conducted on synergies between architectural design and gerontology^[14, 15], directing qualitative assessment of architectural quality and quantitative evaluation of accessibility and usability in architectural spaces.

BIM-based architectural visualization and integration with game engine

Architectural visualization is one of the early fields and low-hanging fruits of BIM implementation. In comparison with traditional paper-based approaches and geometric modeling oriented CAD applications, BIM has a number of significant advantages attributed to the rich content of project information captured in addition to geometry, such as usability, materials properties, and the building process through the project's life cycle^[16]. The virtual reality constructed by BIM solutions provides the ideal context that clients can relate to their living 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^[17, 3].

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^[18]. BIM will have to evolve toward a more user-centered, experience-based design, focusing on interactive spaces rather than focusing on digital representation^[19]. 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^[17]. 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^[17, 16].

Recently, BIM and game engine has also been broadly integrated in pedagogical innovations for learning enhancement and professional training purposes. For instance, Yang^[20] proposed a learning tool to educate non-experts about energy-related design and decision-making; Shen et al.^[21] 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 of heating, ventilation and air-conditioning (HVAC) systems; Ruppel and Schatz^[22] designed a new serious gaming approach based on BIM for the exploration of the effect of building condition on human behavior during the evacuation process; Dib and Adamo-Villani^[23] described the development and initial evaluation of a serious game for learning sustainable building design principles and practices; and Liu et al.^[24, 25] 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.

Research objectives and methodology

Starting as a student course project, this study initially intended to explore innovative BIM implementation in the design for aging scenario, and how the leverage of BIM-game engine enabled visualization and interaction may help enhance student learning outcomes (SLOs) in graphical communication and code compliance. Later, entrepreneurial thinking was incorporated and a prototype was developed to explore business opportunities out of such innovation. Therefore, the overarching goal of the study was to develop a user-friendly, practical, and potentially entrepreneurial solution to elucidate design intentions and avoid typical miscommunications encountered in conventional design for aging workflow. To accomplish this goal, the following objectives are pursued:

- Investigate the critical factors that influence sustainable aging design iteration, communication effectiveness, and feedback mechanism;
- 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;
- Develop the gaming environment that supports robust user-design interaction scenarios tailored for sustainable aging projects.

Students started with literature review on design for aging practices and exploratory survey with local senior people as well as design professionals. Findings from these preparatory tasks were factored into design authoring. Technology selection for model authoring and game engine integration was then performed. Due to the programming skills required, a teaching assistant majoring in computer science was hired to carry on the work of developing the BIM-game engine integration prototype. Figure 1 illustrates the project workflow.

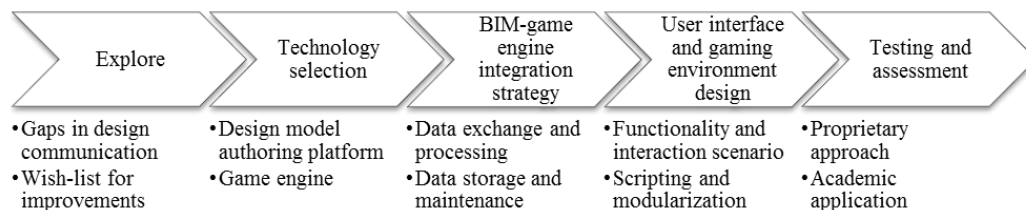


Figure 1. Project workflow with major phases and tasks.

Student exploration of design for aging criteria and best practice

A brief market demand analysis was performed by student groups through a series of interviews and surveys with local design professionals, senior citizens and senior housing investors. 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). Based upon these findings, a generic time/effort mapping was created as shown in Figure 2 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.

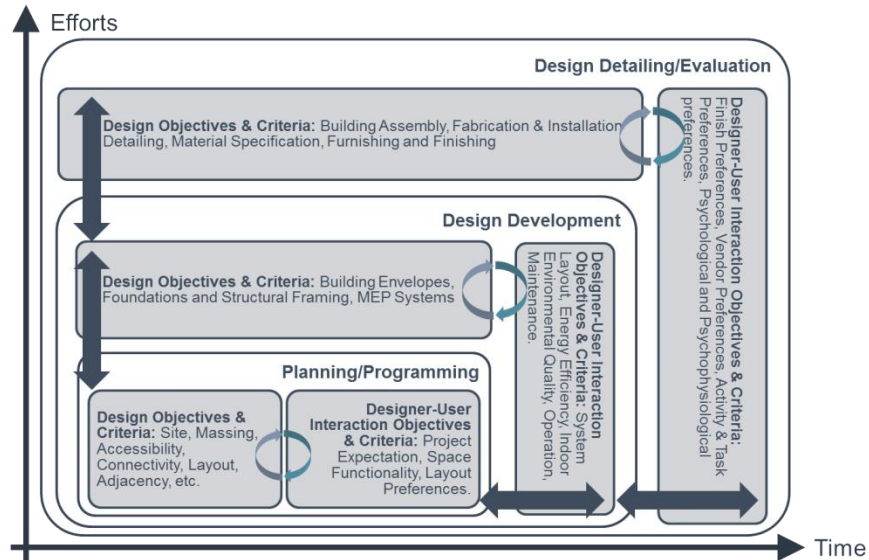


Figure 2. Time/efforts mapping for design criteria and design-user interaction.

The biggest obstacle perceived in existing design for aging practices is the lack of effective design communication for clients to truly understand the design intention, providing that design delivery remains predominantly paper-based in the residential sector. On the other way around, designers seldom receive meaningful feedback from their clients so they could have modified the design to their expectation and satisfaction. Providing the fact that some of the interviewed architects have already been using BIM instead of blueprints, they still feel challenged to get constructive questions from 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 as the panorama renderings could offer, these architects all received positive feedback from their clients, indicating better understanding of the intended design as well. 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.

Technology selection and BIM-game engine integration strategy

Factors that affect the selection of technology are multifaceted, as documented in the literature. For the model authoring platform, there is little competition due to the fact that Autodesk Revit has been the dominant BIM application in the North American market. Revit is intuitive and powerful in terms of modeling capabilities. The constraints of Revit however reside in its interoperability with mainstream game engines. Although Revit supports model export in various 3D file formats, it tends to lose important information such as the relationship between model elements and their textures. The recommended solution as revealed in the literature review is to export a Revit model as a FBX file and edit the texture in 3ds Max, which is another Autodesk product famous for its 3D modeling, animation and rendering capabilities. 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.

As far as the selection of game engines, the most critical consideration 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 DfSA prototype for the Windows platform. The development life cycle for the proposed prototype is illustrated in Figure 3. 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 complete 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. Once the raw prototype was completed, usability testing was conducted through user data collection against predefine performance criteria.

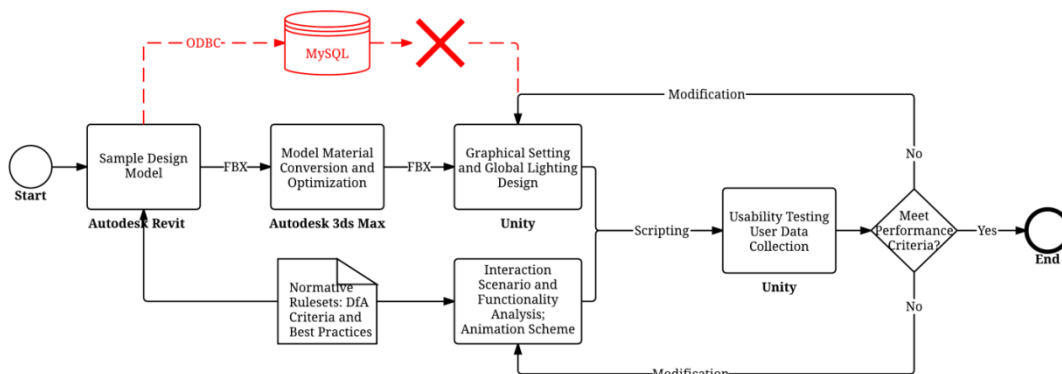


Figure 3. BIM-game engine integration prototype development life cycle.

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 4. The essence of 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 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 purpose 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.

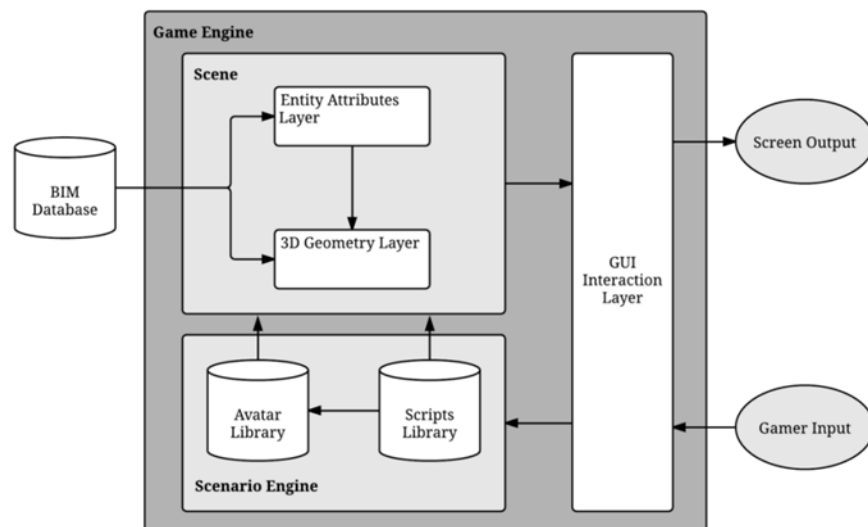


Figure 4. Prototype system architecture.

Student learning outcomes and status of prototype development

At the end of the fall semester of 2014, student groups in the advanced architectural design class produced the sample model with integration of design for aging criteria, as shown in Figure 5. A grading rubric (Table 1) was used to evaluate the student learning outcomes in a simplistic manner. Overall, the assessment results as shown in Figure 6 suggested solid performance of student works. Admittedly such evaluation was biased with the subjective judgement of the instructor, but it provided some insights into students’ perceptions and acceptance of using BIM in performance-based design catering to the needs of the senior population. Students also provided constructive feedback on the current tools and their capacities in facilitating design for aging practices. One of the biggest challenges, and also a very promising venue for improvement is BIM content development: students had a hard time to find appropriate components, such as ADA-compliant furnishing, to put into the model.



Figure 5. Student posters showcasing design for aging models.

Table 1. Design for aging project grading rubric.

Criteria	Poor Points – 5	Below Expectation Points – 10	Meet Expectation Points – 15	Confident Points – 20	Advanced Points – 25
Design Criteria and ADA Compliance	Model shows little (0~<30%) compliance with design criteria and ADA	Model shows some (30%~<60%) compliance with design criteria and ADA	Model shows considerable (60%~<80%) compliance with design criteria and ADA	Model shows major (80%~<90%) compliance with design criteria and ADA	Model shows comprehensive (90%+) compliance with design criteria and ADA
Completeness of Model	Contain only fractional (25% or less) of required model components	Contain about 25% - 60% of required model components	Contain about 60% - 80% of required model components	Contain 80-90% of required model components	Contain 90% or more of required model components
Accuracy of Model	Overwhelming errors in model, e.g. flipped walls, open connections,	Considerable errors in model, more than 5 major mistakes.	Some errors in model, fewer than 5 major mistakes	Very few errors in model, mostly small omissions	Almost perfect, with no obvious mistakes and omissions

	uncut floors, etc.					
Logic of Design and Space Layout	Design is random, no logic or reasoning for space layout at all	Some design criteria reflected, have basic layout of space	Considerable design logic with a few good designation of space functions	Good design logic with clearly identified space functions	Professional space layout and design concept	
Annotation of Design	Little to none annotation was made	Very few annotation made randomly	Some annotation efforts, but incomplete	Quite complete annotation, may miss some components	Comprehensive and accurate annotation of required components	
Detailing and Creativeness	Little to none efforts in creating any detail. No site or furnishing	Very few detail with some random furnishing and a basic site	Basic furnishing and site, with some site features	Good detail of furnishing and site detail	Comprehensive and professional furnishing and site features	

Rubric Statistics Report

Frequency Distribution

CM132 Design for Aging Project Grading Rubric

Criteria	Points	Performance Levels					Number Evaluation	Average	Median	Mode	Std. Deviation
		Poor	Below Expectation	Meet Expectation	Confident	Advanced					
Design Criteria & ADA Compliance	5.00	10.00	15.00	20.00	25.00						
	0%	0%	0%	71%	29%	7	21.43	20.00	20.00	2.44	
Completeness of Model	5.00	10.00	15.00	20.00	25.00						
	0%	0%	0%	57%	43%	7	22.14	20.00	20.00	2.67	
Accuracy of Model	5.00	10.00	15.00	20.00	25.00						
	0%	0%	14%	71%	14%	7	20.00	20.00	20.00	2.89	
Logic of Design and Space Layout	5.00	10.00	15.00	20.00	25.00						
	0%	0%	0%	57%	43%	7	22.14	20.00	20.00	2.67	
Annotation of Design	5.00	10.00	15.00	20.00	25.00						
	0%	14%	29%	57%	0%	7	17.14	20.00	20.00	3.93	
Detailing and Creativeness	5.00	10.00	15.00	20.00	25.00						
	0%	0%	14%	57%	29%	7	20.71	20.00	20.00	3.45	

Figure 6. Design for aging project assessment results.

The proposed DfSA prototype is still under development. Simple interactions have been made available with a semi-completed graphical user interface (GUI) as displayed in Fig. 7. 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.

The Functionality Tray is the current focus of development. Table 2 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. 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 has to be considered. For instance, when the avatar navigates to the kitchen, 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 kitchen design best practices and pertinent code requirements. 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.

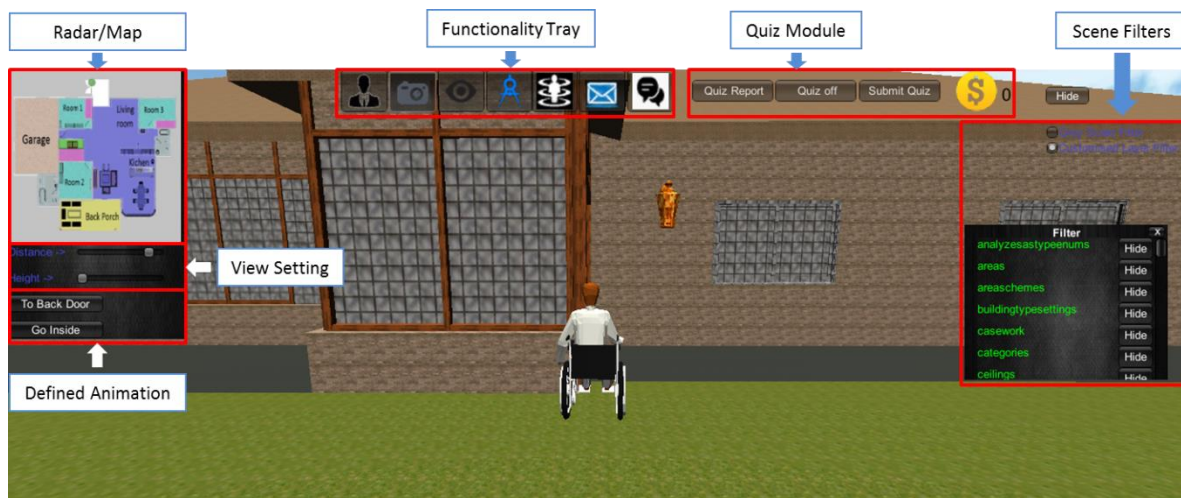









Figure 7. GUI of the proposed prototype.

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. Further development of the prototype into education, training and entrepreneurial product was also suggested. A more comprehensive and formalized assessment is being planned at the moment.

Table 2. Keys and intended functions of the Functionality Tray.

Keys	Intended functions
	Avatar Selector: allows gamers to switch between multiple avatars
	Screenshot: allows gamers to create a screenshot of current scene 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

Conclusion and discussion

The urgency to accommodate an ever-increasing senior population and their housing needs inspires design for aging professionals to utilize cutting-edge technology such as BIM in design innovation. 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. To accomplish this goal, this research built the efforts out of a student project and incorporated engineering entrepreneurial mindsets in the proposition of a prototype based upon BIM and game engine integration. The prototype was created to provide a framework that could transform a static design model into a dynamic and interactive gaming environment, where user-centered and experienced-based conversations between designers and clients would take place. The student learning process, prototype system architecture and design logic were presented and discussed in this paper. A proof of concept was also showcased to give an overview of the GUI and intended functionality developed in the prototype. The main challenge encountered resided in transferring model information 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.

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