Design for sustainable aging: improving design communication through building information modeling and game engine integration

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Abstract

Accommodating the rapidly increasing senior population in the U.S. is a grand effort that necessitates sustainable solutions to address its social, economic and environmental impacts. From the building industry’s standpoint, design for sustainable aging implies creating the physical and service environment that is resilient and adaptable to the needs associated with the aging process. The professional community has responded with well-conceived strategies such as universal and sustainable aging design. In practice, there is an inherent challenge in traditional paper-based design communication when professionals and clients have a hard time to understand each other at the desired level. Recent technological advancement in 3D modeling applications, exemplified by the prevalence of building information modelling (BIM), has reinvigorated sustainable aging design practices. Meanwhile, serious gaming has been gaining recognition as valuable enhancement to academic learning and professional training by effectively engaging participants with meaningful and programmable visualization and interaction. This study proposed to create a unique framework that leverages the integration of BIM and game engine to streamline and contextualize design communication in sustainable aging projects. A prototype framework, Design for Sustainable Aging (DfSA), was developed and discussed in this paper. Essentially, DfSA transforms a static design model into a robust 3D gaming environment wherein design information is preserved while user-centered and experience-based interactions with model components are achieved. DfSA holds the promise to improve design communication by establishing a brand new platform for design presentation meanwhile providing an experiential instrument to elucidate the design intention.

Keywords: Design for aging; communication; building information modeling; game engine; interaction

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1. Introduction

The design-for-aging (DfA) community in the U.S. is facing significant challenges arising from the rapidly increased senior population. Aging in place or sustainable aging, which denotes the ability to remain at home safely and independently while aging [1], is a preferred option among senior citizens to retain as integral and productive members of their communities [2]. To successfully age in place, it is crucial to create the physical and service environment catering to the needs of the senior life. Wu and Handziuk [3] revealed that there were considerable communication barriers with the paper-based approach by designers in interpreting clients’ project expectations and conveying design intentions. Building information modeling (BIM) is an emerging trend in the architecture, engineering and construction (AEC) industry. BIM is the digital representation of both the physical and functional properties of a facility through its life cycle [4]. For designers, BIM introduces a virtual environment that facilitates rapid prototyping and design visualization and communication. Nevertheless, a generic building information model lacks the behavioral information of its components that is needed to provide stakeholders with meaningful feedback when they try to interact with the design and act upon its elements [5]. A game engine such as Unity3D, on the other hand, can engage stakeholders 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. This study pursued the perceived synergies of BIM and game engine and directed the efforts to improve design communication in sustainable aging projects. A prototype was created to investigate factors that affect stakeholders’ visualization and interaction experience in the gaming environment. More importantly, it exemplified sustainable aging strategies by designing better physical and service environments that meet the needs of the aging population, which had a much broader impact beyond the AEC community.

2. Background

According to [6], the senior housing market in the U.S. is currently driven by baby boomers that represent 28% of the total population, own 48% of the homes, and account for 45% of spending on renovations. A recent market trend analysis found that nearly 90% of the senior population chose aging in place, and 80% preferred to stay in current residence [7]. The need to strategically planning for aging in place is statistically justified [8]. The U.S. Census Bureau [9] projected that 83.7 million (21%) of the U.S. population would be over age 65 by 2050.

2.1. Compounded social/architectural implications of sustainable aging

Sustainable aging is a complex geographical process mediated by institutions and other social forces [1]. Housing plays an irreplaceable role in senior life. Human existence is closely related to architectural space, and results in individual patterns of spatial use [10]. The interactions with architectural space, for instance, visualization and usage, supply meaning in the aging process [1]. Appropriate architectural design can also create supportive environments for the elderly [11] and it has a therapeutic effect [12, 13]. The home environment as a spatial expression has to be specially conceived for the elderly [14]. Design professionals embrace these ideologies and make conscious efforts in driving housing design towards aging in place purposes. 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 view when interpreting the residential satisfaction of aging seniors. For instance, [15] 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 [16]. Familiarization with the architectural space has been advocated as a component of sustainable aging in place [17]. Research has been conducted on synergies between architectural design and gerontology [18, 19], directing qualitative assessment of architectural quality and quantitative evaluation of accessibility and usability in architectural spaces.
2.2. BIM and game engine integration

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 [20]. 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 [21, 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 [22]. BIM will have to evolve toward a more user-centered, experience-based design, focusing on interactive spaces rather than focusing on digital representation [23]. 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 [21]. 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 [21, 20].

Recently, BIM and game engine has also been broadly integrated in pedagogical innovations for learning enhancement and professional training purposes. For instance, [24] proposed a learning tool to educate non-experts about energy-related design and decision-making; [25] 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; [26] 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; [27] described the development and initial evaluation of a serious game for learning sustainable building design principles and practices; and [28, 29] 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.

3. Research goals and objectives

Built upon the body of knowledge and best practices, this research pursues a unique case of BIM-game engine integration applied in improving design communication for sustainable aging projects, which has been rarely documented in the existing literature. The goal of this research is to develop a user-friendly, fun, yet versatile gaming environment named DfSA (design for sustainable aging) that enables user-model interaction and stakeholder conversation to elucidate design intentions and avoid typical miscommunications encountered in conventional design workflow.

It is essential for, and a key obligation of, designers in sustainable aging projects to take a user-centered and experience-based approach. The proposed integrative gaming environment transforms a static design into an interactive platform where more meaningful conversation between designers and clients can take place so consensus and solutions can be sought after on the fly.

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.
4. Research approach and methodology

The research starts with an exploratory analysis through interviews and surveys to understand the typical design communication iteration in sustainable aging projects. Insights into current practices will be carried into the development of the proposed DfSA prototype via BIM and game engine integration. The system architecture of DfSA is developed based upon careful selection of information exchange protocols, modeling and gaming engine products. Functionality considerations have taken into account various user-design interaction scenarios, which also lead to the programming and scripting. Fig.1 illustrates the overall research workflow.

![Fig. 1. Research workflow and major tasks.](image)

5. Develop the DfSA prototype

A brief market demand analysis was performed through a series of interviews and surveys with local design professionals, senior citizens and senior housing investors. The biggest obstacle perceived in existing design communication is the lack of an effective mechanism 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 finding was discovered 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 a solution like DfSA could have the potential to significantly improve design communication and client satisfaction. Several local architects expressed interests in testing DfSA once it was developed.

5.1. 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 are selected to create the proposed DfSA prototype for the Windows platform. The development life cycle for DfSA is illustrated in Fig. 2. A sample senior house is modeled in Revit, and exported as a FBX file. The FBX file is further processed in Autodesk 3ds Max 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 has been tested as well. However, this approach proves to be problematic due to the complete loss of model element material property in transition from Revit to MySQL. Major scripting efforts take place after comprehensive interaction scenarios and functionality analysis, which dictates the animation scheme and graphical user interface design. Once the raw prototype is completed, usability testing is conducted through user data collection against predefined performance criteria.

![Fig. 2. DfSA development life cycle.](image_url)

5.2. System architecture and gaming logic

The DfSA 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. The system architecture of DfSA is illustrated in Fig. 3. The essence of system architecture design for DfSA 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, DfSA provides 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 will be 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.
6. DiSA prototype proof of concept

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

![System architecture of DiSA.](image)

![GUI of DiSA prototype with a sample design model.](image)
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. 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. **DfSA** can also be utilized as instructional instrument in college curricula and the quizzes will be a possible measure for assessment.

<table>
<thead>
<tr>
<th>Keys</th>
<th>Intended functions</th>
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<tbody>
<tr>
<td>Avatar Selector</td>
<td>allows gamers to switch between multiple avatars</td>
</tr>
<tr>
<td>Screenshot</td>
<td>allows gamers to create a screenshot of current scene and save it in a default folder</td>
</tr>
<tr>
<td>First/Third Person View</td>
<td>allows gamers to toggle between first and third person views</td>
</tr>
<tr>
<td>Measurement</td>
<td>allows gamers to measure distances in the model</td>
</tr>
<tr>
<td>Teleportation</td>
<td>allows gamers to jump between place-marked locations</td>
</tr>
<tr>
<td>Email</td>
<td>allows gamers to email collaborators</td>
</tr>
<tr>
<td>Commenting</td>
<td>allows gamers to provide feedback on the game design</td>
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The **DfSA** 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. Possible development of the **DfSA** prototype into education/training and entrepreneurial product was also suggested. A more comprehensive and formalized assessment is being planned at the moment.

**7. Conclusion and discussion**

This research investigated an important application of advanced design modeling in a profound social-economic issue – sustainable aging. The key question to be addressed was how to develop a framework to improve design communication so that sustainable aging design could be accomplished and optimized. In pursuit of this goal, this research integrated BIM and game engine to create a DfSA 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 system architecture and design logic of DfSA 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 DfSA.

The main challenge encountered in DfSA development 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.
References