OwnerHistory, etc. Each attributes has its own data type. For example, the data type of GlobalId is string, the data type of OwnerHistory is entity called IfcOwnerHistory. Among the attributes of IfcRoad entity, one of the most important entities is IfcRoadComponent. It is inherited into different structural members like IfcRoadWay, IfcRoadBase, IfcRoadBed, IfcRoadCurb and IfcRoadDrainageSystem. The IfcRoad entity is also inherited into IfcMunicipalRoad, IfcHighwayRoad, and other entities as subentities. The geometry and location information of the infrastructure construction components are stored as attributes of the entities.

SEMANTIC WEB and RDF

Semantic web technology is the next generation web standard to describe internet resources for information sharing purpose. Using semantic web, the semantic meaning of internet resources can be read and understood directly by computers algorithms. In this project the main stream semantic web standard Resource Description Framework (RDF) is adopted to depict the internet based project resources. The RDF file is also organized in XML format, which means it contains a lot of objects and attributes. First, the ontologies of project data model area created with RDF. Then several instances are generated based on the original ontologies. For example, the general GIS and BIM data model are created as two RDF ontologies as <owl:Class> objects. Base on the reality project information, two entities <rdf:Description> are generated to describe the GIS and BIM related remote resources with a specific attribute <si:link> showing the URI link. Web service module can read the above information and conduct data transfer behavior. Figure 2 shows an example of RDF file with project information, BIM and GIS links.

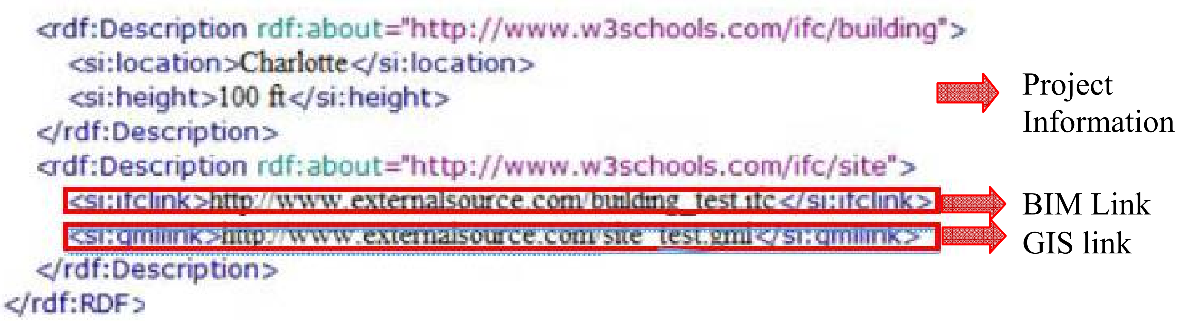

Figure 2. Example of RDF file with project information, BIM and GIS Links

CASE STUDY

The case study was conducted and applied to a highway construction project with earth excavation/embankment, and road pavement. The total length of the project is 318 meters and the total construction cost was $17,182,637. The quantities of cut and fill are output from the IFC model based on the information obtained from the IFC entities. The general method of quantifying cuts and fills is based on the existing topography elevation in GIS data by locating the IFC model at different elevations.

The goal of the earthwork simulation is to minimize the earthwork by balancing the cut and fill operation. As the road elevation changes, the earthwork volume increases or decreases. The total range of the elevations was from 1,800 feet to 3,600 feet. And the least amount (11,824 cy of excavation) of earthwork operation is found at the elevation of 3,100 feet. The excavation varied from 1,200,000 cy at 1,800 feet to 165,000 cy at 3,600 feet and embankment from 13,062 cy at 1,800 feet to 548,200 cy at 3,600 feet.

CONCLUSIONS

In this paper, a highway data model in IFC based BIM data model was used to store infrastructure information. Then, Geographic Information System (GIS) file was used to store geographic information, such as land boundaries, environmentally sensitive regions, and topographic data. In order to easily retrieve and integrate those two types of data format, the semantic web data schema was implemented to exchange data in infrastructure (BIM) and geographic information (GIS) in two ways, which greatly improved the interoperability of the current approach.

The developed data integration system was applied in highway construction for earthwork calculations located in the southern part of Korea and consists of earthwork and road pavement infrastructure. The related project data retrieved by semantic web file from remote BIM and GIS files showed a seamless data integration without creating a laborious data schema process. A prototype system was implemented to process initial retrieved data which is then analyzed by the genetic algorithms to perform multiple cut and fill simulations. An optimal construction equipment plan is generated based on the simulation result.

REFERENCES

Banks, J. H., (1998), “Introduction to transportation engineering”, WCB/McGraw-Hill Company, Singapore

BuildingSMARTAlliance (2010), “Introduction to BIM – GIS Integration”, http://projects.buildingsmartalliance.org/files/?artifact_id=3592

Chae, M.J., Lee, G.W., Park, J.W., Kim, J.R., and Cho, M.Y., ″3D Work Environment Modeling for the Intelligent Excavation System (IES)” Construction Research Council, 2009 April, ASCE, pp. 497–505

Cheng, Dan, et al. "Emergy evaluation perspectives of an irrigation improvement project proposal in China." Ecological Economics 70.11 (2011): 2154-2162.

Cheng, J., Deng, Y., Das, M., and Anumba, C. (2014) Evaluation of IFC4 for the GIS and Green Building Domains. Computing in Civil and Building Engineering (2014): pp. 2216-2223.

Goktepe, A. and Lav, A. (2003). ”Method for Balancing Cut-Fill and Minimizing the Amount of Earthwork in the Geometric Design of Highways.” J. Transp. Eng., 129(5), 564–571

Hare, W. L., Koch, V. R., and Lucet, Y. (2011). “Models and algorithms to improve earthwork operations in road design using mixed integer linear programming.” Eur. J. Oper. Res., 215(2), 470–480.

Irizarry, J., Karan, E., and Jalaei, F. (2013), ntegrating BIM and GIS to improve the visual monitoring of construction supply chain managementOriginal Research Article Automation in Construction, Volume 31, May 2013, Pages 241-254

Karan, E. and Irizarry, J. (2014) Developing a Spatial Data Framework for Facility Management Supply Chains. Construction Research Congress 2014: pp. 2355-2364.

Kim, E., Jha, M., Schonfeld, P., and Kim, H. (2007). ”Highway Alignment Optimization Incorporating Bridges and Tunnels.” J. Transp. Eng., 133(2)

Kim, H., Orr, K., Shen, Z., Moon, H., Ju, K., and Choi, W. (2014). ”Highway Alignment Construction Comparison Using Object-Oriented 3D Visualization Modeling.” J. Constr. Eng. Manage., 140(10)

Nassar, K., Aly, E. A., and Osman, H. (2011). “Developing an efficient algorithm for balancing mass-haul diagrams.” Autom. Constr., 20(8),1185–1192.

Shi, J. and Liu, P. (2014) An Agent-Based Evacuation Model to Support Fire Safety Design Based on an Integrated 3D GIS and BIM Platform. Computing in Civil and Building Engineering (2014): pp. 1893-1900.

Yabuki, N. and Shitani, T. (2005) A Management System for Cut and Fill Earthworks Based on 4D CAD and EVMS. Computing in Civil Engineering (2005): pp. 1-8.

Towards Understanding End-user Lighting Preferences in Office Spaces by Using Immersive Virtual Environments

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ABSTRACT

Buildings and their systems are primarily designed based on several assumptions about end-users' requirements and needs, which in many cases are incomplete and result in inefficiencies during operation phases of buildings. With advancements in fields of augmented and virtual reality, designers and engineers have now the opportunity to collect information about end-users' requirements, preferences, and behaviors for more informed decision-making during the design phase. These approaches allow for buildings to be designed around the users, with the goal that the design will result in reduction of energy consumption and improved building operations. The authors examine the effect of design features on occupants' preferences and performance within immersive virtual environments (IVEs). Specifically, this paper presents an approach to understand end-users' lighting preferences and collect end-user performance data through the use of IVEs.

INTRODUCTION

Buildings' energy use accounts for roughly 45 percent of the energy consumption in the United States (EPA 2013). Buildings and their systems are generally designed to operate based on code-defined occupant comfort ranges to ensure satisfactory temperature, luminance, and ventilation, and standardized (recommended) set-points to accommodate occupants' needs, and comfort levels (Brandemuehl and Braun 1999). Previous research has shown there is a weak correlation between these codes and the actual occupant reported satisfactory ranges. Many times these standard set-points do not fulfill comfort and satisfaction in buildings (Barlow and Fiala 2007; Jazizadeh et al. 2012). Research has also suggested that by tailoring the design of a building's elements and systems around occupants, there is a potential to reduce the energy consumption of buildings, as well as increase occupant satisfaction (Janda 2011; Klein et al. 2012). User-centered design (UCD) has shown to be an effective approach to improve a final product based on end-users' needs in many domains, including software design and automotive industry. Researchers have proposed the need for the architecture, engineering, and construction (AEC) industry to adopt the concept of UCD by involving end-users early on during the design phase (Bullinger et al. 2010). Although previous studies have used behavioral models to simulate occupant behaviors (including preferences, requirements, comfort levels, etc.) during the design phase to improve the energy efficiency of buildings (Hoes et al. 2009; Reinhart 2004), these studies do not usually provide a realistic representation of occupant behavior. As people spend approximately 90% of their time indoors (Frontczak and Wargocki 2011), it is crucial to study the interaction between occupants and their indoor environment in order to both increase occupant satisfaction and reduce energy consumption. To address this issue and to develop designs that are centered-around the occupants, there is a need for accurate measurement of occupant preference and behavior.

The AEC industry has adopted the use of building information modeling (BIM) to visually communicate and exchange information among parties involved in a project and end-users. Although BIM provides 3D models and the necessary geometric and semantic information about the building and its components, prior research illustrated that BIM does not provide the necessary spatial feelings that the end-user might need to provide design feedback (Kozhevnikov 2008; Shiratuddin et al. 2004). In order to effectively allow end-users to fully understand the design, IVEs have opened the door for engaging end-users in the design process of projects by combining the strengths of pre-construction mock-ups that provide a sense of presence to users and BIM models that provide the opportunity to evaluate alternative design options in a timely and cost efficient manner. Furthermore, by creating a better sense of realism through its one-to-one scale, building engineers and designers can incorporate IVEs in their work processes as a tool to measure end-user behavior, understand the impact of design features on behavior, and receive constructive user feedback during the design phase. The authors' previous research has suggested that these environments have the potential to provide a sense of presence found in physical mockups and make evaluation of numerous potential design alternatives in a timely and cost-efficient manner (Heydarian et al. 2015).

As part of their research, the authors aim to improve the design process through informed design decision making as a way to improve overall building performance by using IVEs. The goal is to collect end-user data, incorporate them within the design decision tools, methods, and technologies and measure the impact of designing with end-user data on overall design quality. Specifically, the authors aim to examine different design features' (e.g., spatial geometries, wall and window geometries and types, and etc.) effects on end-users performance and preferences. Moreover, the authors aim to examine such effects by manipulating different design features within IVEs in order to create actual human profiles based on their preference and performance. These profiles then can be used to better design environments that increase end-user satisfaction and possibly reduce the total energy consumption.

As a first step towards this goal, in this paper, the authors study lighting settings (luminance and illuminance) in an office environment in order to examine the effect of manipulating different design features on user performance. Previous research has identified lighting as one of the major factors that influence occupants' performance in indoor environments (Boyce et al. 1989; Romm 1994). For instance, (Fisk and Rosenfeld 1997) has shown that activities, such as reading speed and comprehension (Smith and Rea 1982; Veitch 1990), locating and identifying objects, and writing are highly affected by luminance, amount of glare, and spectrum of light. This stream of research suggests that designing environments based on people's lighting preferences have the potential to affect their productivity and performance. Prior research has also shown that personal preferences have more of an effect on people's choice of light source than the available daylight when occupants use their offices for a short period of time (Correia da Silva et al. 2013). Being able to design environments with satisfactory lighting levels based on the occupants' preferred settings not only could improve user satisfaction but also could potentially reduce the total energy consumption in buildings.

This paper presents an approach to collect data about end-users' different lighting preferences and performance in order to form profiles. The lighting preferences (natural and artificial) of participants are measured within an IVE along with their performance on doing office-related activities (reading and identifying objects) in participant's preferred lighting settings. The paper presents the research methodology, the IVE system for data acquisition, initial pilot profile data, and discussion on the proposed approach and planned future work.

METHODOLOGY

The profiles are based on end-users' lighting preferences and performance in their preferred light settings. These parameters are measured based on the choices end-users make to adjust the lighting levels and their performance on a set of assigned visual tasks.

In order to create user profiles, a number of participants were recruited to measure their preferred light settings in an office environment in order to perform a set of office related tasks. Once participants chose their most preferred environment based on the different lighting levels, the 3D models' settings (artificial light settings, geographical location, time of day, etc.) were imported into a simulation software in order to collect the light maps and lux values of the entire office area. Along with the lux values, their performance data (reading and comprehension) was collected.

Experiment Design. Although there are many design alternatives that could affect the amount of lighting levels in an office space (e.g., number, type, and size of windows, type of light bulbs, geometrical design of the room, reflective surfaces, etc.), the authors designed their experimental environment similar to one of the office spaces of an actual office building. As a result, a 150 square meter (10 m x 15 m x 3 m) office space was modeled for this experiment. The designed office space consisted of three windows (a set of blinds per window) and 12 light fixtures (three light bulbs per fixture) with the possibility of having three artificial light settings (one light bulb on, two light bulbs on, and three light bulbs on).

The modeled environment was used to measure the participants' most preferred light settings, as well as their performance on a set of assigned tasks (reading speed and comprehension) in the same lighting environment. The participants were placed in a dark room (Figure 2a) and were instructed to setup the room's lighting levels based on their most preferred settings (in terms of use of natural light, artificial light, or a combination of both, as well as the amount of lighting). The participants had the options to open/close each set of blinds to increase/decrease the availability of natural light and turn the light switches on/off to control the artificial light levels in the room.

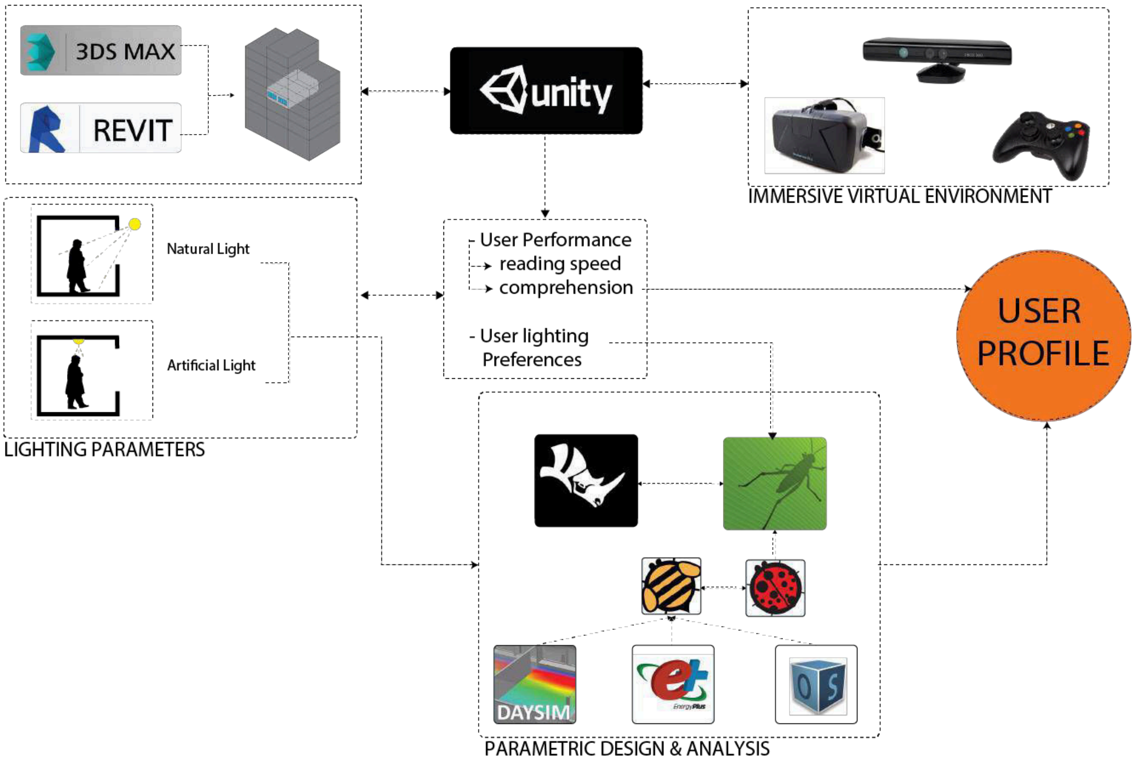


Figure 1 – Process for data collection and processing

Model and Apparatus. The base structure and geometry of the office space was designed in Revit© 2015. 3ds Max© was used to optimize the model, add materials, furniture, artificial and natural lighting, texture, shadows, reflections to the office space. The model was then rendered to texture (creating light and texture maps) in order to achieve a photorealistic 3D model. Once all 32 different lighting possibilities (different combinations of three windows and three artificial light settings) were rendered and all lighting and texture maps were acquired, the model was imported to Unity game engine as an FBX file. Figure 2 shows a sample of these models with different light settings. In order to ensure the lighting levels in the office were realistic and represent real-life environments, 32 different light maps were generated through Ladybug and Honeybee plugins (open source plugins for Grasshopper3D – Rhino plugin) (Roudsari et al. 2013). Ladybug allows for a full range of environmental analysis in a single parametric platform and Honeybee connect Grasshopper3D to EnergyPlus, Radiance, Daysim, and OpenStudio software for building energy and day lighting simulation with an intend to provide parametric platform based on many features of these simulation tools.

Unity was also used to connect (1) an Oculus DK2 Head-Mounted Display (HMD) and a Xbox-360 controller together and link them to the imported 3D model; (2) create different interactive options that a participant could have with the physical model (e.g., turning the light switch on/off, opening/closing blinds, picking up objects); and (3) script animation and changes in scenes (e.g., lighting reflections, changes in texture) based on the participants' interactions with the virtual office space. To increase the sense of presence and allow participants to realistically interact with the IVE, the Oculus Rift DK2 positional tracker was used to track the participants' neck displacement (3 Degrees-of-Freedom - DoF), the HMD was used to track the head rotation (3 DoF), and the Xbox-360 controller was used to navigate through the room, providing 6 DoF. Figure 1 illustrates the modeling steps and the apparatus.

a. All blinds closed & all lights off b. All blinds open & all lights off c. All blinds closed & all lights on d. All blinds open & all lights on

Figure 2 – Sample of different lighting levels in the IVE

Experimental Procedure. In order to collect participants' lighting preferences and performance in participants' preferred environments, a pilot experiment (as a proof-of-concept) was conducted with 15 participants. The participants were undergraduate and graduate students at the University of Southern California between the ages of 20 and 32. Prior to the experiment, the participants were provided with an IRB (Institutional Review Board) approved consent form. They were briefly informed about the experiment without disclosing any information that would potentially affect their responses and behavior.

Once the participants reviewed and agreed to the consent form, they were provided with a brief training on how to use the Xbox controller for navigating within the space and interacting with the model. They were then asked to put the HMD on and walk in the room; the initial lighting conditions in the room were set to be dark (Figure 2a), with just a minimum amount of light available (light coming through and around the blinds) that would allow the participants to see the objects in the room. As part of their training, in order to get more familiar with the office environment, learn how to navigate within the space, and visualize the changes in light intensity levels by opening/closing blinds and/or turning the light bulbs on/off, they were asked to take a few minutes to interact with the blinds, the light switch, and the objects within the room (e.g., how bright the room would get if one or two blinds were opened along with having one of the light bulbs on). Once they felt comfortable with the space, they were asked to set the lighting levels to their most preferred levels for performing office related tasks such as writing or reading a paper. They were then provided with a short passage (approximately 350 words) to read. Once completed, they were asked to remove the HMD and answer a few questions related to the passage.

Additionally, people's preferences for light sources and intensity levels may differ depending on individual differences (e.g., mood, gender, personality, etc.). One major individual difference is one's concern about the environment. The authors also administered a questionnaire that assessed the participant's degree of environmentally-friendly behavior. Upon completing the questionnaire, they were thanked and dismissed. Figure 3 shows a participant navigating within the IVE and interacting with different light settings.

Figure 3 – A participant setting-up her most preferred lighting setting in IVE

END-USER LIGHTING PROFILES

Once the participants' lighting preferences were collected, their preferred settings were matched to the generated light maps. For instance, if participant A's preference was to have three blinds open and two light bulbs on, the already generated light map that represented that setup was selected. It is important to note that these light maps are generated based on the lighting intensity values from 3ds Max along with the exact geographical location and time of day that were inputted into the honeybee plugin (Figure 4). The light maps provide a set of lux values for the specific light settings of the room based on the participants' preference.

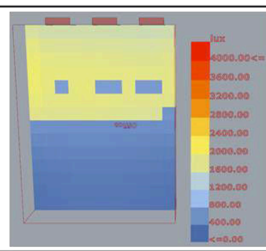
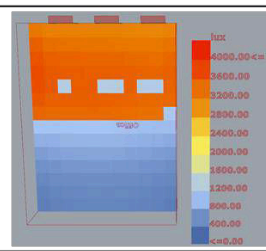
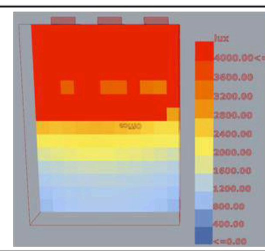
Participant	A	B	C
Comprehension (%)	75	100	75
Reading Speed (word/s)	2.5	3.1	3.2
Preferred Light Setting	3 Blinds Open 1 Light Bulb on Each Fixture	3 Blinds Open 2 Light Bulb on Each Fixture	3 Blinds Open 3 Light Bulbs on Each Fixture
Preferred Light Map			

Figure 4 – Example of lux values and light maps based on participant profiles. The light maps represent the room from the top view.

In addition to these light maps, the participants' reading speed and comprehension were measured (Figure 4). The participants' reading comprehension was measured based on the number of questions they answered correctly; their reading speed was measured in words read per seconds. Since there were only four comprehension questions, the researches chose 75 percent (at least three out of four) accuracy as a reasonably good performance level. Figure 4 shows the profiles for three different participants in terms of comprehension, reading speed, preferred light setting, and preferred lighting map.

CONCLUSION, LIMITATIONS AND FUTURE WORK

The ability to design buildings around the needs and comfort levels of occupants can result in better interactions between buildings and their occupants, leading to higher end-user satisfaction and more importantly a reduction in building energy consumption. The work presented in this paper focuses on understanding end-users preference and performance data using IVEs with the long term goal of integrating this data to the design phase of buildings. In this paper, an approach to collect end-users preference and performance data was presented by allowing the participants to choose their preferred light settings within IVEs.

The presented work in this paper is the first step to create end-user profiles based on their lighting preferences through the use of IVEs. This work thus additionally contributes to the already existing work on IVE, by suggesting that IVEs can be used to study human preference and performance. This paper presents pilot data for a few profiles. In order to develop geometries and improved office spaces based on end-user preferences, there is a need for a large amount of data to create end-user lighting profiles. In future work, the authors will collect this data in order to form more specific, accurate profiles of a population. In addition, different architectural design options (e.g., type and size of windows, materials, etc.) could affect the available lighting levels in an office environment. In future work, the authors will evaluate different effects of these design features on users' preference and performance.

Lastly, these end-user lighting profiles can be used as inputs into multi-agent design systems to develop new alternatives and improved models that are based on end-users needs and preferences. By being fed these profiles, the multi-agent system will be able to design environments that fit the specific preferences of end-users. In addition to collecting more data on the presented approach in this paper, the authors will also evaluate participants' lighting preferences when provided with initial lighting settings in order to examine the relationship between initial lighting setting and end-users preferences. In this way, the authors can examine how initial lighting conditions increase/decrease people's propensity to change the light as well as their performance in the chosen lighting conditions. By studying human behavior through IVEs, this future research hopes to devise a methodology, through which energy consumption in buildings can be reduced.

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REFERENCES

Barlow, S., and Fiala, D. (2007). "Occupant comfort in UK offices—How adaptive comfort theories might influence future low energy office refurbishment strategies." *Energy and Buildings*, 39(7), 837-846.

Boyce, P., Berman, S., Collins, B., Lewis, A., and Rea, M. (1989). "Lighting and human performance: A review." *Washington (DC): National Electrical Manufacturers Association (NEMA) and Lighting Research Institute*.