10.20378/irb-58502

Illustrating Energy Related Properties of Buildings Using a 3D-Game-Engine

Thomas Rist, Jens Müller
University of Applied Sciences Augsburg
Augsburg, Germany
{Thomas.Rist, Jens.Mueller}@hs-augsburg.de

Abstract. The paper presents first steps towards the deployment of a 3D-game engine for the interactive exploration of energy-related properties of buildings, such as heat transfer properties of different materials, or the effect of settings of HAVAC (Heating, Ventilation, and Air Conditioning) control systems on a building's in-door climate. We present a number of relevant information goals in the domain of energy efficient buildings and relate them to illustration techniques which could be used to increase a user's understanding of and interest in the topic. It is assumed that a repertoire of visually attractive illustration techniques will pave the way for novel game-like exploration systems for non-expert users in the domain of energy-efficient architecture and construction.

1 Motivation

Energy efficient buildings are becoming increasingly important given the desired political and societal shift away from fossil fuels. Various tools have been developed to assist practitioners and researchers in the domains of architecture and construction engineering to explore and evaluate energy-efficiency technologies and renewable energy strategies in new or existing buildings. For an impressive list of more than 400 such tools see the catalogue maintained by the Office of Energy Efficiency and Renewable Energy of the US Department of Energy [1]. However, designed for professional users, such tools are often too complicated and too expensive for a broader user group including potential private home builders as well as owners who want to inform themselves about existing and upcoming energy-efficiency technologies. The importance of this target group is given by its sheer size, though variations exist from one country to another [2].

Our aim is to allow non-expert users to access and experience in a playful way energy-related properties of buildings, construction materials, and building usage patterns by means of a popular 3D game engine (e.g. Unreal or Unity).

For the purpose of a case-study we cooperate with the principle constructor (i.e., a consortium consisting of the council of the German town Königsbrunn, a regional energy services provider, a company for residential development, and our university) of a highly energy efficient prototype building, the "Visioneum" [3]. The Visinoeum is a so-called energy plus building, i.e., a building that over the year produces more electric energy through roof-top solar power panels than it consumes for heating/cooling, lighting, and electric home appliances. The surplus of electric energy may be either fed into the power grid, or likewise used for fuelling electric vehicles in its neighbourhood. When completed in 2016, the Visinoeum will be open to the public and host an exhibition space as well as an office for energy consultancy. In addition, our university will use it as a test-environment for research on new energy efficient materials and building automation technologies. For our project on interactive 3D illustration of energy- related properties we take advantage of the Visioneum's 3D CAD data.

2 Approach

In our attempt to explain and illustrate energy relevant properties of a building, its materials, and usage patterns we need to bring together expertise from different disciplines, building design and engineering, 3D illustration, and computer game development.

2.1 Identifying Information Goals with Domain Experts

In a working meeting with colleagues from the department of construction engineering we compiled a list of themes which are of special interest when discussing energy performance of buildings; among those themes are:

- Heat transfer and insulation properties of building parts (such as walls, ceilings, staircases, windows, doors etc.) depending on the materials of which they are made of, as well as of their structural properties, such as surface area.
- Functioning and effectiveness of the HAVAC (Heating, Ventilation, and Air Conditioning) control system of an inhabited building at different seasonal requirements.
- Orchestration of solar energy generation, battery-based storage, and smart consumption by means of an intelligent building control system.
- The integration of an energy plus building in a neighbourhood which consists of conventional as well as further energy plus buildings.

- Sustainable, resources-preserving building design, use of renewable materials, and recyclability after demolition.

Next, the domain experts formulated questions and information objectives related to afore mentioned themes. Thereby, identified information goals go beyond mere explanations of how certain technologies work.

Regarding properties of building parts raises the question of what are the effects when a part gets replaced by another part made of other materials. For example, different materials for walls and windows affect heat transfer but there may be additional effects as well, such as a change in noise dampening or the need for modifications in the building's overall construction. Thus, making a user aware of consequences and trade-offs caused by material choices is an important information goal in this context. In the case of the air ventilation system the information goal could be to make the user aware about possible consequences of human interventions, such as opening a window.

2.2 Development of Interactive Illustration Techniques

Technical illustration, a discipline at the cross section of visual art, science, and engineering, has brought about a multitude of visualisation styles, rendering techniques, and visual metaphors to visually communicate technical subject matters to a nontechnical audience. Inspirations and guidelines for the production of handcrafted illustrations can be found in textbooks [4], [5], [6], as well as in online collections [7], [8]. Popular types of technical illustrations are:

- annotations of objects, e.g. by text labels to name depicted object;
- exploded views, e.g., to show the spatial arrangement of the parts of an assembly;
- cut-away views and transparent views, e.g., to enable a look through or inside non-transparent objects;
- cross-sections, e.g., to show the structure of layered materials;
- ghost or phantom objects, e.g., to show selected locations of an object movement,
- variations of level of detail, e.g. to draw the viewer's attention from background objects to foreground objects;
- non-realistic and false-colour rendering of surfaces, e.g., to encode otherwise invisible object properties, such as colour coded heat-maps an object's surface temperature distribution, or to emphasise or deemphasize certain object parts through artificial shading effects, such as hatching;

- inclusion of meta-graphical objects, e.g., arrow symbols to indicate the direction of a moving physical object, or lines to visualise sound waves or energy fields.

The above mentioned techniques have been developed for the purpose of static printable technical documentation. Nowadays, the production of technical illustrations benefits from powerful graphics software packages. Nevertheless, the majority of technical illustrations are still static images even if distributed digitally and viewed on computer screens, or they are rendered as a sequence of images to be viewed as a video short.

In contrast, interactive illustrations are dynamic media as they allow viewers to explore depicted subject matters through instant changes of view points, and modifications of object properties. Interactivity is brought in by means of a user interface that enables variation of parameters to control type, style, and display of an illustration. In some approaches parameters have to be set prior to the display of the illustration. For example, a user may set parameters for an automated camera-flight around or into an object (or building), such as start and end point or the speed of the camera movement. Other settings allow for more direct control, such as user-controlled 3D walk-throughs, or instant interventions, such as manipulating objects. Within the discipline of computer graphics interactive versions for all of the above mentioned techniques have been developed. Examples include the dynamic rearrangement of textual annotations [9], modification of render style [10], or cut-away views [11], [12] while performing view point changes.

So far, only a few attempts have been made to exploit techniques of interactive illustration to the domain of energy-efficient buildings. Schreyer and Hoque [13] use thermography images of buildings taken by an infrared camera as textures for rendering a simplified 3D model of the corresponding building. This way, a series of thermography images can be explored as a virtual 3D tour around the building. Work at Autodesk Research [14], [15] combines information of a BIM (Building Information System) with measured data collected through a sensor network to better understand a building's performance during usage. They have developed a number of 3D-techniques for illustrating heat distribution and heat flow within an office space. For example, gradient shading is applied to surfaces to visualize thermal values of selected spatial zones. An interesting approach to visualize sensor recordings has been proposed by Wittenburg et al. [16]. They represent time series of sensor readings in the shape of sliced 3D-scupltures which are positioned on a 2D floor plan to show the locations of the sensors in a building.

Our approach shares similarities with work conducted in the EEPOS project [17]. As part of the user interface for neighbourhood energy service providers and users they integrated the Unity game engine. Users can explore 3D models of apartments and receive real-time as well as historical data of energy consumptions through text and chart displays which are integrated into the 3D model. However, our approach is not on building monitoring and thus goes beyond the display of energy consumption or generation. Rather, users are invited to modify building properties and learn about the effects by means of interactive illustration.

2.3 Adding Elements of Game Play

To familiarise non-expert users with topics related to energy-efficiency of buildings we believe that adding elements known form computer games can be beneficial, since one can draw on:

Users' likely familiarity with computer games: Many people have already played computer games and are thus already familiar with popular principles of game play and interaction styles found across different computer game genres. Our Visioneum show case features a 3D environment to be explored by users through navigation in virtual 3D space with a free-roaming camera, manipulation of objects in the environment, and triggering events that produce perceivable outcomes. Such elements are found in a number of game genres, including real-time action, adventure, and maze games. Also, we expect that users will easily understand how to control the application using a gamepad.

Users' intrinsic motivation to play: For leisure games Ryan et al. propose "… that events and conditions that enhance a person's sense of autonomy and competence support intrinsic motivation, whereas factors that diminish perceived autonomy or competence undermine intrinsic motivation." [18, p 349]. Many serious games approaches draw on the assumption that embedding a learning task -such as teaching a technical subject-matter- into a game context can motivate players to engage in them similar as leisure games do. However, a recent meta-study by Wouters and colleagues did not confirm an increased motivational appeal of serious games compared to other learning methods per se [19]. As a possible reason they point out that learning games are often part of a curriculum and therefore give players less autonomy with respect to when they play and for how long they want to play. Fortunately, this factor will be less relevant in our Visinoneum showcase as the visualisation system is for use on a voluntarily basis.

3 State of Development and Outlook

Our project is still at an early stage of development. So far, we extracted from the Visioneum's CAD data a simplified model suitable for import into the Unreal 4 graphics engine (cf. Fig. 1 a). Starting from the information goals identified by the domain experts, we are currently experimenting with different types of interactive visualisation techniques. For example, to explain the effect of replacing a window with another one that has other insulation properties, we may deploy particles to visualize heat flows.

Our current implementation does not yet constitute a (serious) game. However, we intend to use it as a test-bed for adding elements of game play. For instance, the goal to inform a user about the effect of different materials insulation could be transformed into a player's "mission" to detain as much as possible heat particles in the building. To do so, the player would have to pick appropriate materials for the building parts, and while doing so, learn about their properties and possible constraints on their combinability.

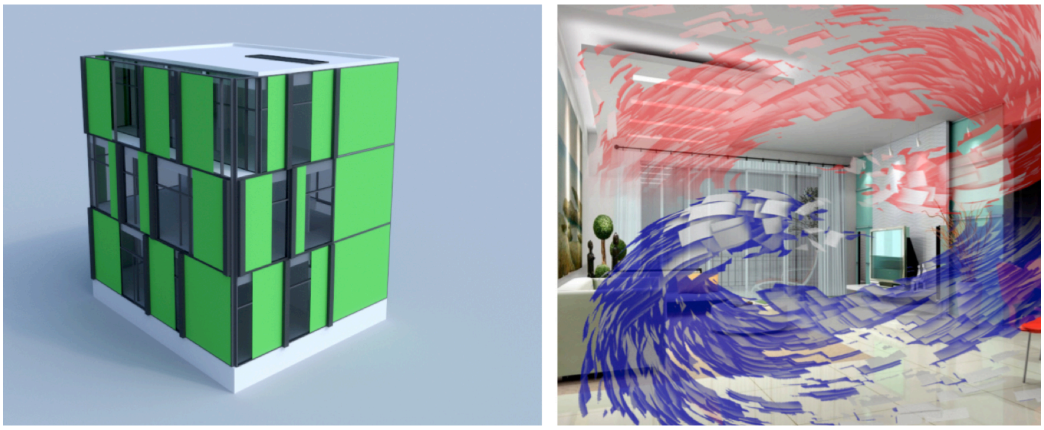

Fig 1: (a) 3D model of the Visioneum, (b) Particles forming 3D- arrows to depict air circulation in a room

Further inspirations for adding game elements can be found in energy games [20]. A recent study by Grossberg and colleagues surveyed 53 games which aim to influence behavior around energy efficiency and sustainability [21]. Focusing on 22 games that are or could be part of an energy efficiency program, they discuss how these games address essential game elements, such as progress paths, levels, and triggers, real-time feedback, interaction and competition among players, and achievements and rewards. To meet the preferences of different player types [22], there may be a need to offer a choice between different exploration styles.

In addition, we plan to evaluate our hypothesises that users will (a) quickly be able to familiarize with the exploration system, and (b) appreciate the exploration experience.

Acknowledgements

We like to thank the members of our project group Kevin Aust, Dennis Falkner, Markus Heimbach, Ines Kossack Marlen Materna, Alexander Mersdorf, Carmen Merz, and Martin Willam. Special thanks goes to our colleagues from the department of architecture and construction engineering Georg Sahner and Johannes Rieger for their valuable inputs. The work is supported by the BMBF-funded German-New Zealand research collaboration IT4SE, grant number 01DR12041. Further information on IT4SE can be found under www.it4se.net

References

[1] Office of Energy Efficiency and Renewable Energy (EERE). Building Energy Software Tools Directory: http://apps1.eere.energy.gov/buildings/tools_directory/
[2] Wikipedia.org. List of countries by home ownership rate. http://en.wikipedia.org/wiki/List_of_countries_by_home_ownership_rate
[3] Visinoeum Energie+: http://www.visioneum.de
[4] Thomas, T.A. Technical Illustration. McGraw-Hill, 1960.
[5] Martin, J. Technical Illustration: Materials, Methods and Techniques , MacDonald Orbis, 1989.
[6] Yee, R. Architectural Drawing: A Visual Compendium of Types and Methods. John Wiley & Sons; 4th edition, 2012.
[7] Technical Illustrators: http://technicalillustrators.org/
[8] Pinterest Inc.: http://www.pinterest.com
[9] Ali, K., Hartmann, K., and Strothotte, T. Label Layout for Interactive 3D Illustrations. Journal of the WSCG, 13:1–8, 2005.
[10] Gooch, B., Sloan, PPJ., Gooch, A., Shirley, P., Riesenfeld, R. Interactive technical illustration. Proceedings of the 1999 symposium on Interactive 3D graphics, 1999.
[11] Feiner, S., and Seligmann, D. Cutaways and Ghosting: Satisfying Visibility Constraints in Dynamic 3D Illustrations. The Visual Computer, 8(56), 1992, pp. 292-302.
[12] Diepstraten, D., Weiskopf, and Ertl, T. Interactive Cutaway Illustrations. Computer Graphics Forum, 22(3):523–532, September 2003
[13] Schreyer, A.C., and Hoque, S. Interactive Three-Dimensional Visualization of Building Envelope Systems Using Infrared Thermography and SketchUp. Proceedings of InfraMation, Vol.9, 2009.

[14] Hailemariam, E., Glueck, M., Attar, R., Tessier, A., McCrae, J. Khan, A. Toward a unified representation system of performance-related data eSim 2010 Conference Proceedings: IBPSA-Canada eSim Conference. 2010, pp. 117 - 124.

[15] Attar, R., Hailemariam, E., Breslav, S., Khan, A., Kurtenbach, G. Sensor-enabled Cubicles for Occupant-centric Capture of Building Performance Data. Proc. of ASHRAE Annual Conf. 2011

[16] Wittenburg. K., Laughman. C., Nikoiski. D., Sahinoglu. Z. Advanced Visual Interfaces for Smart Energy: Focusing Where it Matters Most. Proc. of the AVI 2014 Workshop on Fostering Smart Energy Applications through Advanced Visual Interfaces. 2014, pp. 31-34

[17] EEPOS project website, http://eepos-project.eu

[18] Ryan, R. M., Rigby, C. S., and Przybylski, A. The Motivational Pull of Video Games: A Self-Determination Theory Approach. Motivation and Emotion, 30, 2006, pp. 347–365.

[19] Wouters, P., van Nimwegen, C., van Oostendorp, H., van der Spek, ED. A meta-analysis of the cognitive and motivational effects of serious games. Journal of Educational Psychology, Vol 105(2), May 2013, 249-265.

[20] Canada Science and Technology Museums Corporation. Energy Games. http://energy.techno-science.ca/en/games-videos/energy-games.php

[21] Grossberg, F., Wolfson, M., Mazur-Stommen S., Farley K., and Nadel, S. Gamified Energy Efficiency Programs American Council for an Energy Efficient Economy (ACEEE), 2015. Online: http://aceee.org/research-report/b1501

[22] Bateman, C., Lowenhaupt, R., Nacke, LE. Player Typology in Theory and Practice. Proc. of DiGRA 2011.