Development and Evaluation of a Prototype Software Application for the Visualization of Environmental Data

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Abstract. This paper presents EnViz, a prototype software application for the visualization of environmental data. The rationale for the development of the application is given, together with the methodology for collecting the data. A technical description of the software is provided, with a presentation of new features and their relevance. Two case studies are presented, and their relevance in the testing of the software is discussed. Visualization results from the application of the software are included. Particular attention is paid to the testing and evaluation of the application by real users. The methodological approach is described and the results of the tests are presented. The paper concludes by interpreting the results and pointing towards directions for further research on the topic.

Keywords. 3D visualization; building performance; COLLADA; environmental data; post-occupancy evaluation.

INTRODUCTION

The importance and ubiquity of the environmental aspects in contemporary architecture can hardly be overstated. From zero-carbon, to low-energy, to climate-sensitive design, architects, engineers, and associated construction professionals have to take into account a variety of environmental factors during design. In addition, client requirements with regard to internal comfort conditions are constantly increasing. The assumption is that buildings will provide a constantly improving internal environment while at the same time constantly reducing their environmental impact and energy requirements.

In order for these expectations to be fulfilled, designers need to be able to predict accurately how different design proposals will perform. This requires of architects to have at the very least an appreciation of environmental issues from the very start of their training. As a result, aspects of building physics combined with other elements of environmental science can now be found at higher education from the undergraduate level.

In the office, building environmental simulation software has moved from being the domain of the consulting specialist, to standard tools employed at the very early stages of design. Practically all major vendors of architecture and engineering software count at least one building environmental simulation package amongst their offerings [1][2][3].

Simultaneously, researchers keep developing new tools, looking into more specialized aspects [4].
The application of those in real-world case studies allows one to gauge both the advantages and limitations of the approach (Milne, 2008). At the same time, the introduction of new technologies such as Building Information Modeling has opened a new field for further study (Tajin Biswas et al., 2008).

This increasing importance of simulation, in both research and practice has been widely recognized, with Rivka Oxman suggesting the term *Formative Design* in order to describe an emerging paradigm of a morphogenetic approach that relies heavily on computational simulation tools (Oxman, 2008).

**POST-OCCUPANCY EVALUATION**

The establishment of desired performance standards however, inescapably leads to a need for measurement of the actual performance of a completed building. Typically this is conducted via post-occupancy evaluation surveys (POES), which aim to evaluate the building performance systematically on a range of issues such as health and safety, functionality, efficiency, and satisfaction with the aesthetic result (Federal Facilities Council, 2002). With regard to environmental aspects, emphasis is placed on thermal comfort, with air quality, lighting levels, and acoustic performance also being important concerns.

While POESs can rely on *perceptional* data, collected by interviewing building users to gauge opinions and experiences, many researchers place more emphasis on physical, objectively measured data (Nicol et al., 2012). Physical data is typically collected via data loggers with sensors that measure properties such as air temperature and relative humidity at specified intervals [5]. As such loggers are typically low cost and easy to use, allowing large volumes of data to be collected and analyzed statistically in specialist software packages.

The importance of post-occupancy evaluation is obvious, even more so in performance-driven architecture where simulation consumes significant resources and can drive the design process.

Anecdotal evidence however suggests often this importance is not recognized. Designers might “walk away” from a project after completion, without revisiting the work later in its lifetime. Facilities managers and Estates services might commission POESs, but the results might not be easily communicable to senior management. In higher education, the interpretation of such data can be a complex task, suitable more for research work at graduate level than an undergraduate course.

The software we present in this paper is an attempt to address some of these issues.

**A SOFTWARE APPLICATION FOR ENVIRONMENTAL VISUALIZATION**

*Data visualization*

The development of EnViz began in 2011. One of us (Altan) had substantial experience in the collection of POES environmental data, however he found that it was often difficult to communicate those to both students and clients. Another (Patlakas) suggested that this could be due to the different approaches adapted by environmental scientists and architects. While the former concentrated on data collection and analysis, the latter placed emphasis on the design process which typically relies heavily on the visual element. As for stakeholders without a background in a built environment discipline, large data volumes can appear abstract, if not inscrutable.

Visualization can be a powerful tool for comprehending large volumes of data. They not only enable the viewer to work with data on various scales, but also to discern patterns that are not immediately apparent, thus facilitating hypothesis formation (Ware, 2000). In the built environment, standard information visualization techniques are often combined with 3D models to provide in-context information. There is however an emphasis on the urban scale, with the issues that this can bring as documented by a number of researchers including most recently Morton et al. (2012). Various initiatives have enhanced 3D visualization with information-rich con-
tent, either on an urban planning level (Aschwanden et al., 2012), urban and architectural design level (Peng, 2011) or for other aspects of the built environment such as environmental impact assessment (Lai et al., 2010).

Despite this prolific production however, there has been no attempt to visualize POES data in a 3D model context. Instead, POES data are visualized only on simple 2d graphs, as produced by standard spreadsheet applications such as MS Excel (Figure 1).

Features and improvements
EnViz was developed to change this, introducing model-specific 3D visualization for POES data. The software is developed in Java SE, utilizing the LWJGL [6] library to implement the OpenGL framework. Open-source standards are used throughout, with COLLADA [7] being the 3D model format, and XML used for the POES data.

The first prototype version was completed successfully in 2012, with the software utilized in a small case study, a trial run conducted with three user groups consisting of a total of 31 participants, and the results presented in workshops and conferences (Patlakas and Altan, 2012).

The first iteration of the software, and the feedback provided from the workshop and conference participants identified some core features for further development. The development team identified the following features as high-priority, with immediate benefits for the users and potential to expand the topics identified in research:

1. Multiple model handling
2. Import data directly from spreadsheets and/or native logger format
3. “Smart”, automatic, linkage between 3D models and data
4. Internal space evaluation based on established thermal comfort criteria
5. Layer-based selection of multiple spaces, with turn on/off capabilities
6. Enhanced 3D navigation capabilities

From those features, the automatic linkage was achieved via a metadata layer provided in the 3D model and associated logger data. The thermal criteria are customizable, however default values are provided for non-specialist users, based on the CIBSE guidelines (2008). The rest of the features were implemented utilizing standard software engineering practice, with development concluding in early 2013.
APPLICATION ON CASE STUDIES

Case study selection
In order to test the latest version of the software, suitable case studies were required to have the following characteristics:

- a sizeable building portfolio with a certain amount of data logger measurements, to test the software's capabilities to handle significant volumes of models and associated logger data
- a combination of spaces with and without data to cross-check the effectiveness of the automatic logger placement
- a climate-sensitive design that would make the case study relevant also to the environmental design community

Two case studies were identified for this process, and they are summarily described below.

Large-scale industrialized housing
This case study concentrates on a large-scale housing development called Villas de Pendregal, in the city of Morelia, Mexico. It consists of approximately 12,000 houses, built with an industrialized building system, designed for linear production, and applicable to undeveloped large territorial expansions. The development is particularly suited for environmental design research as it consists of identical designs from reinforced concrete. The application of the software presented here is based on a study of 12 identical buildings, 3 from each major orientation. For this, recordings of temperature and relative humidity of the indoor environment were taken over two seasons (Cool/Warm). In total 580,608 readings were recorded (Becerra, 2013). Based on the drawings supplied by the environmental design researcher, volumetric models were developed in SketchUp and exported in COLLADA. The logger data were imported directly from the provided Excel spreadsheets. The process run without problems and illustrated that the software is fully able to handle such volumes of both models and data. For the testing process more than 250,000 measurements have been processed. The visualizations created exceed 200, including both models and animations (Figure 2).

Mixed-use university building
The second case study is Jessop West, a mixed-used
university building, and part of the University Sheffield campus. This was selected as it was considered important to test the software’s capacity of handling large models with a wide variety of spaces and the associated data and metadata. In addition, it provided the opportunity to evaluate the application’s usability in the visualization of complicated models. In order to evaluate the building’s actual performance, the Building Environments Analysis Unit [8] of the Sheffield School of Architecture conducted a two-year survey collecting data from a variety of spaces from the five floors of Jessop West. A total of 38 spaces were monitored, collecting a total of more than 150,000 recordings, all of which have been processed in EnViz (Figures 3 and 4).

**ENGAGEMENT WITH USERS**

**Workshops**

The importance of verifying the usability of a software application is a fundamental tenet of Human-Computer Interaction (HCI). Shackel (1990) as quoted by Preece et al. (1994) formalizes usability by identifying four core components: learnability, ease of use, flexibility, and user attitude. Though it is generally accepted that a small number of expert users will identify core usability faults or interface bugs (Te’eni et al., 2007), testing with non-expert users is considered necessary to gauge the performance of software. Practically all HCI authors stress the importance of selecting test users who approximate the targeted average user as closely as possible.

For the evaluation of this phase of development, three workshops were organized. Two of those took place in Sheffield (UK) with a total of 17 graduate and research students with a background in architecture, engineering, and the built environment, and concentrated on the Jessop West. The third workshop took place in Morelia (Mexico) and consisted of 11 academics and professional architects. This mix was considered representative of the user groups EnViz aspires to engage and assist.

The workshop participants were asked to complete a small number of tasks, designed to reflect typical aspects of research with POES data, while allowing for comparison of the effectiveness of EnViz compared to the spreadsheet-based approach currently adapted by researchers. Specifically, users...
were asked to evaluate the temperature and humidity conditions in certain spaces for specific dates and times.

After the conclusion of these tasks, the participants were asked to provide their views on the spreadsheet-based method and EnViz, with regard to a certain range of parameters. They were also asked to compare the two and state their preferred method of working based on their experience.

**Evaluation**

Huang et al. (2009) state that visualization efficiency can be evaluated quantitatively based on three variables: response accuracy (RA), response time (RT), and mental effort (ME). The response accuracy of the users based on the two tasks they were asked to complete were measured, in order to provide a comparison of their performance in each method. As the aim was to compare an established method (spreadsheet) with the one suggested by the development team (EnViz), measuring the response time for individual tasks was not considered of primary importance. Instead, this was taken into account by providing the same time for each task in both methods for all users. As such, the users’ performance results reflect both response time and response accuracy.

It was not considered of vital importance to measure mental effort in a quantitative fashion. Instead it was assumed that this would reflect on the users’ views for each approach, thus providing a qualitative indicator.

The users were asked to evaluate each approach on the following aspects:

- Easy to learn
- Easy to use
- User productivity
- Effectiveness of communicating the data
- Allows to evaluate the building as whole
- Usefulness in sustainable design

A semantic differential scale was provided, ranging from Very Bad to Excellent. Besides providing their preferred system, the users were also asked to provide the reasons for this view.

**Performance results**

The results paint a generally favorable picture for EnViz. With regard to response accuracy in identifying the correct temperature, participants performed...
clearly better when using the visualization as opposed to the spreadsheet (Figure 5).

It should be noted that none of the participants had used EnViz before, while all of them had a reasonable familiarity with Excel, with some having a certain level of expertise in dealing with POES data. Also, the introduction to each task was kept to a minimum (typically five minutes). Users were not given the opportunity to practice the EnViz features first, nor where they provided with detailed information of the color map scales. This was done on purpose as one of the aims was to determine how intuitive the application is, and how productive users can be starting from a zero level of expertise. Thus it is reasonable to assume that given some modest training and practice users can be expected to perform significantly better. The experience of the members of the development team that have engaged with the application on a long-term basis supports this assumption.

**Evaluation results**

In the qualitative evaluation of the two systems, the 3D visualization approach emerges as a clear winner. Participants rated it as better in all the required aspects (Figure 6), including all the users that did not manage to complete the second task in the required time frame.

A significant majority of users mentioned it as a better method of working (Figure 7). It is telling that after being exposed to the 3D visualization approach, no participant voted in favor of the spreadsheet only, but instead the rest of the participants that didn’t select EnViz opted for “both”.

**CONCLUSION AND DIRECTION FOR FURTHER RESEARCH**

The development and testing of EnViz suggests that there is significant potential for the use of in-context 3D visualization for the display of time-dependent building data, providing advantages with regard to comprehension and comparison, as well as hypothesis formation and validation. It also implies that it is possible to develop a purpose-built system with a minimal training overhead, avoiding the “software fatigue” that makes many users reluctant to try new applications.

With regard to further software development, users have suggested a range of features, mostly corresponding to usability included in 3D modeling packages. Some, such as being able to move models around to allow for easier comparison appear to offer immediate benefits. There is also potential both in integrating such features in existing pack-
ages (especially in BIM) as well as taking advantage of web-based technologies such as WebGL to create a dynamic system that records and visualizes data in real-time.

It is also important to note that the system can be replicated for different building data types with a small overhead. The development team has built color maps for visualizing light, sound, and air quality data, thus enabling a full color map system. The introduction of other visualization aspects (e.g. textures) is a promising field for further research.

Finally, other types of data could be visualized with a similar approach. We are currently working on a version to visualize electricity, gas, and water usage data, while colleagues have suggested space utilization and circulation levels as areas of interest for further development.

REFERENCES


Figure 6
Comparative evaluation of the two methodologies.
Figure 7
Preferred approach.

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