Temporal Visualization of Building Occupancy Phase

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Abstract

Numerous interrelated factors affect building performance. Physical building elements, internal and external climatic conditions, and building occupants interact through time to impact the way a building consumes resources. Currently, however, leading building performance software programs represent much of the information related to these factors in text or chart form. Such representations make it difficult for building designers, operators, and other stakeholders to understand how this information interacts through time. This paper describes an early prototype called OViz, which creates spatio-temporal representations of (observed and/or assumed) geometry, occupancy, environmental, and performance data, and enables users to visualize and explore how this information changes through time in a 3D environment. We are testing the extent to which these visualizations help designers and operators understand and detect meaningful patterns and interrelationships amongst the information and whether they can support design and operations decisions.

Introduction

Building performance is a complex function reliant on multiple temporal factors. Building performance simulation and monitoring programs describe these factors in terms of three main groupings of variables through time: *building components and zones* (architectural, electrical and mechanical), *environmental conditions* (outdoor and indoor), and *occupant behavior* (schedules and loads). Each variable is described using a variety of data types, including geometry, numbers, percentages, text, states (on/off, open/shut) etc., all of which can vary over time. The complexity of this function makes it difficult for teams of people to understand

interrelationships between factors, and thus design and operate high performance buildings with accuracy.

During the design phase, project teams need reliable estimates of the energy performance of their projects. As with any model, the validity of results is dependent on both the precision of the calculation engine and input variables. Designers need to make and clearly document and communicate reasonable assumptions for input variables when trying to accurately model and simulate the energy performance of their designs. During the occupancy phase these values become known, but the data, if collected, can become immense and difficult to analyze. Building operators need to interpret this data to best understand how their building, occupants, climate and performance are interacting through time.

Current professional practice, however, lacks tools to usefully communicate and analyze these temporal variables. Existing interfaces for energy performance simulation and monitoring tools generally display information regarding occupant behavior, environmental conditions, and building component states in separate, static, text or chart representations (See Figure 1). These interfaces make it difficult for building designers and operators to fully comprehend the relationships between temporal variables and their direct and indirect contributions to energy consumption. These tools could benefit from better visualizations to assist the user to interpret inherent patterns and relationships amongst multi-dimensional data.

Figure 1: VisualDOE interfaces - lighting schedules (left) and temperatures (right).

Visualization of temporal factors affecting building performance, whether during building design or occupancy, offers several challenges. Each factor can be described in terms of many variables, each of which may have different time periods, granularity and value types, and can relate to different sets of zones and component types. Particularly when constructed in combination with building geometric representations, visualizations may contain an overwhelming variety of synchronous data. Our work seeks to better communicate and analyze the data currently input into and output from design and occupation models to allow users to better interpret patterns and relationships between the information. OViz is an application that uses representation techniques including billboards, text, 3D rendering, and 4D animation to dynamically and concurrently display information about occupant behavior, the environment, building component states, and energy consumption. We are testing the extent to which synchronously displaying these data sets within one spatio-temporal

arena enable users to detect more useful patterns and relationships that impact building performance.

Figure 2 describes our process using the Narrative notation (Haymaker and Suter 2006). A project team collects or models (actual or assumed) datasets representing inputs and/or outputs of energy simulations such as occupant behavior, environmental conditions, building component states, and energy consumption. Next, a user constructs visualizations of this data by associating data types and instances to a variety of visualization techniques. A user can synchronously explore these temporal variables within the building's 3D geometry at zone or building level by animating the data through time, doing side-by-side comparisons, and filtering out aspects of the visualization to hone in on specific data. We are testing the extent to which exploration of the data enables project teams to successfully discern or interpret implicit patterns and relationships in the datasets that may impact building performance.

Figure 2: Narrative of the OViz method.

Points of Departure

Spatio-temporal modeling is being explored in a variety of Architecture, Engineering and Construction (AEC) specific applications. Our points of departure for spatio-temporal visualization are based on two perspectives: construction and Geographic Information Systems (GIS) visualization. For construction visualization, a common approach is known as 4D CAD, where user can playback construction duration and visualize construction status on 3D models based on construction schedule (Koo and Fischer 2000). In 4D CAD, main visualization techniques are color-coding and visibility. This approach has been extended to include other construction attributes and visualized in various ways including vector fields

representing workflow and excavation visualization (Akbas 2003), and equipment animation (Kamat and Martinez 2005).

A second perspective is visualization of temporal data on GIS, where exploratory spatio-temporal techniques help query the temporal data and explore changes in relation to other variables (Andrienko et al. 2003). To extract complex data patterns and relationships, statistical analysis (data clustering, matrix ordering) has been combined with visualization techniques (Greiling et al. 2005; Guo et al. 2006). Ideas from this perspective are applicable to occupancy visualization on 3D models, except that the additional spatial dimension adds to data complexity, primarily occlusion of visualized data. One can project building floors in the 3D model as separate 2.5D layers, visualizing temporal data as in GIS. However, this view results in a loss of 3D configuration of the building in relation to the occupant use. The work presented in this paper builds on top of a 4D construction application (Akbas 2003) and implements techniques from information visualization (Ware 2004) and spatio-temporal GIS visualization (Andrienko et al. 2003).

Existing models of building components, environmental conditions, and energy performance provide source data for OViz. Using Building Information Modeling (BIM) techniques, users build a database of physical and functional characteristics on 3D geometric models. Models of exterior and indoor environmental conditions as defined by governing bodies, e.g., Typical Meteorological Year (TMY) data and prescriptive code-based standards (ASHRAE-90.1, IECC) provide additional source data. These data sets and/or monitored data, along with building energy simulation results (DOE-2, EnergyPlus) and/or monitored energy use are fed into OViz. Thus, using modeled and/or observed input assumptions and outcome performance data, OViz visualizes multi-dimensional building occupancy and performance.

By visualizing building occupancy, OViz contributes to growing research in AEC modeling “virtual occupants.” Yan et al 2006 work defines goals, social traits, perception, and physical behaviors of virtual users. Their methodology includes “an agent-based approach, where the behavior of virtual users is determined through a hierarchical structure of rules.” Pan et al 2006 uses motion planning to analyze user behavior in regard to building egress. Garrett et al 2006 are studying the use of sensor networks in building automation through simulated models with the goal to successfully balance (simultaneously optimize) user comfort and energy savings through “intelligent lighting implementation.” Arens et al 2006 are developing the Advanced Thermal Comfort Model to predict thermal comfort and thermal perception. Simulation and animation of occupant behavior and comfort are currently out of our scope; however, our work does visualize building occupants per zone over time.

Implementation of OViz

The input of OViz is observed or simulated temporal data related to occupant, environment, and energy consumption, and a 3D building model. We store these values over time in a relational database. Once the performance data is read by OViz, each temporal variable is internally represented as a sequence of states with associated timestamps (Figure 3). This representation is efficient in terms of memory

cost because it stores values independent of time steps for visualization. In addition, calculation of values for a visualization time is simple and efficient, as it only requires linear search for the corresponding timestamp for each temporal variable.

Since geometry and various temporal datasets are merged in OViz offering many alternate views, flexibility for building the visualization is crucial. Built on the visualization engine of GSim (Akbas 2003), OViz provides interactions similar to 4D CAD. Typically, the user adds any necessary geometric detail in the input 3D model (such as occupants and representative equipment). Input into OViz, the user can reorganize the 3D model by dragging components into a user-defined hierarchy called *4D component tree*. The remaining steps for preparing visualization are associating temporal variables with nodes in 4D component tree using simple drag-drop paradigm, and assigning visualization types.

We used the following visualization techniques (Also see Figure 3):

- Visibility. Objects under the associated node appear/disappear based on the current value or the percentage of the value out of the variable range.
- Color coding. Objects related to a variable are assigned color based on its current value and the color-coding palette. User can change the value range and colors for the color-coding palette.
- Text. Contains the current value of a variable and can be shown as 2D text overlaid on the 3D model or 3D text placed close to the associated objects.
- Time-series graphs. Reveal temporal data trends for a variable. In addition to separate windows, OViz allows placement of multiple time-series graphs at once as *billboards*, 2D objects always facing the camera in the 3D view, next to related zone on the 3D model. These graphs contain current visualization time as a vertical line and current value as text.
- Vectors. Particularly suited to visualize building flow variables represented as vectors over time. Vectors are drawn on the 3D model as arrows with measurement location reflecting the start point, direction reflecting the component, and size reflecting the magnitude.

Users can explore the patterns and relationships in the following ways:

- Temporal navigation. Using a time slider, the user may play forward or backward or slide to a particular time instant to explore states of focused components. User may change increments for each time step, or playback a specific time of day.
- 3D filtering and navigation. User can apply 3D navigation such as changing visibility, changing viewpoints, and using clipping planes.
- Comparative analysis. User can compare multiple datasets side by side by opening two separate applications with the same 3D model and different databases. These two applications are linked such that the playback times in both are synchronized.

Figure 3: Example visualization techniques in OViz. Sample temporal variables for each technique are listed. Variables, stored internally as states with associated timestamps, may have different time periods and time increments.

Findings

Initial findings suggest that disparate building operations data viewed synchronously in a 3D environment enables users to discover, interpret and understand meaningful patterns. Our test data set was recorded and observed for select temporal variables during a week long pilot study in the Global Ecology Building on Stanford University Campus. The temporal variables were selected based on previous work (Clevenger and Haymaker 2006) characterizing occupant impact on building performance in DOE-2-based energy simulations. We have begun to use OViz to assist in further analysis of this impact. Figure 4 shows a synchronous comparison of professional assumptions (as modeled in DOE-2) versus observed information for building occupancy at the Global Ecology Building. The difference in magnitude of the two input data sets is revealing, showing that the predicted occupancy is an order of magnitude higher than the actual performance during this point in time. Such visualization provides a “reality check” for modeling assumptions, a dynamic visualization of building operations, and the opportunity to identify discrepancies between estimated and actual energy performance. A designer or building operator could use such visualizations to adjust design or operational

strategies to better fit occupancy (i.e., calibrate energy estimates, adjust electric light zones, and/or establish optimal building start-up times.)

Figure 4: Comparison of modeled (left) and actual building (right) occupancy for the Global Ecology Building, August, Wednesday, 9:15am. By running these models synchronously, users can observe several differences: in reality, the building is not at full occupancy (fewer occupants on right), in reality an occupant may enter and not turn the lights on (no yellow fixtures on right), in reality plug loads may remain high while occupancy low (purple computers on right).

Figure 5 illustrates our use of billboards in visualization, displaying occupancy count and electric lighting usage for the conference room, and revealing that short duration in occupancy results in longer periods of lighting usage (lights left on in an afternoon meeting are turned off by the nightly sweep hours after occupant departure.)

Figure 5: Time-series charts for occupancy and electric lighting usage by zone.

Conclusions and Future Work

This paper describes our work to develop a method to use spatio-temporal visualization techniques to integrate information about occupant behavior, the environment, building component states, and energy consumption. We are developing the tool OViz within an integrated 4D environment so that we might begin to infer causal relationships and patterns amongst this information. OViz strengths include providing users the ability to explore the environment to detect patterns and relationships in the simulated or observed datasets. While not industry tested, we have observed that the process increases transparency, brings more information into focus,

and provides a platform for parallel observations. While these benefits are compelling, collecting good data sets remains a challenge. Translating energy simulation results and assumptions into OViz datasets is relatively easy. However, building data sets from observations is expensive, requires expertise and is prone to technical difficulties and/or subjectivity issues. There is also an opportunity to expand the models being visualized. For example, representations of occupant preference (e.g., illuminance levels, thermal comfort) might be included.

OViz provides a general purpose test-bed for spatio-temporal visualization on 3D models. Future work may include developing data aggregation methods to summarize performance variables; simulation and animation of dynamic behaviors of occupants, and application of flow visualization techniques for additional overlays. We hope to learn how observed patterns and relationships can be used to create more realistic and useful occupant models. Going forward we will combine these visualizations with statistical techniques to further explore relationships between building performance variables.

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