Towards Visualization of Simulated Occupants and their Interactions with Buildings at Multiple Time Scales

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Abstract

While most building simulation tools model occupancy using simple 24-hour profiles, researchers are applying machine learning and other advanced modeling approaches to simulate individual occupants and their interactions with buildings. For building designers to fully benefit from these increasingly advanced occupant models, visualizations must ultimately reveal subtle yet informative patterns contained in the simulation results. As a step in this direction, we focus on 3D animation and the challenges that arise when multiple time scales are involved. Specifically, we explore the use of stylized computer animation to clarify occupant movement, the use of cueing to draw attention to key events, and an original clock widget to consolidate time-related information.

1. INTRODUCTION

Numerous experts have pointed out, through informal observations and formal experiments, that humans can have a dramatic effect on the energy required by the buildings they occupy. This understanding has motivated researchers to apply machine learning, complex scheduling algorithms, and other advanced modeling approaches to simulate individual occupants and their interactions with buildings. These detailed models may soon begin to replace the simple 24-hour profiles used in most building simulation tools intended for sustainable design.

This paper is concerned not with development of advanced occupant models, but rather with the visualization of the simulation results they produce. To understand the role of visualization, it is important to note that simulation results comprise not only a final set of calculated quantities such as heating and cooling loads; they also contain subtle yet informative patterns. One example of such a pattern is a high overnight heating load following certain afternoons in which a particular window is manually opened and left open. Simple tables and plots may suffice to show that the overnight heating load is excessive, but they may not provide an explanation. An advanced visualization tool is more likely to reveal that the root cause of the problem is a poorly designed room which overheats under certain conditions, inducing occupants to keep the window open. The room might then be redesigned to prevent overheating, or repurposed such that it is occupied late in the day when the cooler outdoor air will remind occupants to close the window. This example illustrates that in order for designers to fully benefit from increasingly advanced occupant models, visualization techniques must advance as well.

As a step towards developing effective visualization tools that reveal subtle patterns in occupant simulation results, we focus on 3D animations representing real-world events that unfold over different time scales. The emphasis on multiple time scales reflects the fact that humans can move between rooms or perform short actions in a matter of seconds, whereas longer activities require several minutes or a few hours. Humans also vary their behavior over the course of a day, between days, and between seasons. Naïve attempts to include different time scales in an animation tend to result in complex and rapidly changing scenes, undermining one’s perception of motion, events, and time. To address these challenges, we borrow from computer graphics, cognitive psychology, and human-computer interaction. Specifically, we explore the use of stylized computer animation to clarify occupant movement, the use of cueing to draw attention to key events, and an original clock widget to consolidate time-related information.

2. RELATED WORK

2.1. Occupant Simulation

Experts who record and analyze the day-to-day energy-related actions of building occupants tend to reach the same general conclusions: that occupant behavior has a significant impact on building energy requirements; that this behavior is highly variable and therefore hard to predict; and that more realistic occupant models are needed. According to Haldi (2013), the performance of two identical buildings can vary by roughly a factor of two due to diversity in occupant behavior. Therefore, in the same work, diversity is modeled using probabilities derived from eight years of observed window-opening behavior. Urban and Gomez (2013) report that real-world manual thermostat adjustments, recorded over winter in 82 residential units, show that the standard ASHRAE 90.2 model is likely to oversimplify occupant behavior and underestimate heating loads.

Three Ph.D. theses written in the last decade suggest a trend in academia towards increasingly detailed occupant models. Bourgeois (2005) shows how simulations which distinguish between individual occupants can be used to predict the performance of both manual and automated lighting control systems. Page (2007) proposes a method for simulating rooms as they alternate between vacant and occupied states. Because the state transitions are generated randomly based on probabilities derived from measured occupancy data, Page's method represents an example of machine learning and a clear departure from the static 24-hour profiles used to estimate occupancy in most energy modeling tools. Tabak (2008) demonstrates an alternative to machine learning: a complex scheduling algorithm that accounts for the role of each occupant in an organization, the tasks they perform alone and with other occupants, and the layout of a building. A journal paper by Hoes et al. (2009) combines the work of Tabak and Bourgeois and shows that increasing the level of detail of an occupant model may significantly change energy use predictions.

Narahara (2007) approaches occupant simulation from an architectural perspective as opposed to an engineering point of view. The idea is that the observation of simulated occupants may provide various insights into the design of a building, such as the level of privacy offered by each space. Goldstein et al. (2010) also strive to address the needs of designers. They propose a machine learning method which outputs randomly generated schedules of occupant activities reflecting both real-world measurements and architect-supplied personas. This work is extended in Goldstein et al. (2011) to provide a location for each activity that accounts for a building's layout.

Because buildings must be designed to support the day-to-day activities of their occupants, and because early design decisions are widely believed to have a disproportionately large impact on a building's ultimate energy requirements, we anticipate further model developments reflecting a vision of designers as expert practitioners of occupant simulation.

2.2. Visualization of Building Simulation Results

One may expect widespread interest in the modeling and simulation of a particular domain to be followed by a growing interest in visualizing the resulting data. In the field of computation fluid dynamics (CFD), for example, a recent literature review by McLoughlin et al. (2010) cites no fewer than 70 original contributions to the visualization of flow. However, despite recent advances in modeling, the visualization of simulated occupants and their interactions with buildings has received little attention.

In claiming that the visualization of occupant simulation results has received relatively little attention, we must point out that the numerous 3D animations of simulated crowds address only a few of the many aspects of building design. Crowd simulations tend to emphasize survival instincts and adversity towards collisions. While these aspects of human behavior are critical for the study of pedestrian flow and building evacuation, a multitude of other factors are of greater importance for predicting and minimizing a building's energy requirements. Furthermore, animations of crowd simulations are generally restricted to relatively short time periods over which the movement of each simulated occupant is clear. Visualizations of energy-related occupant simulations must be effective for both short and long time scales. The reason is that a single action may require only a few seconds while patterns of human behavior and energy use may unfold over hours, days, or seasons.

A number of techniques proposed for the visualization of measured data could be repurposed to show simulated data instead. Hailemariam et al. (2010) demonstrate various ways to superimpose building performance data on renderings of 3D building geometry. For example, simple geometric shapes are used to represent occupants detected by motion sensors. Also, walls, floors, and furniture are colored by interpolating data from nearby temperature sensors. Rassia (2008) uses flow maps to show the recorded paths of 56 real-world occupants carrying location tracking devices. Although the flow maps do not represent time and are not presented as the main contribution of the paper, they have the potential to inform design and could easily be adapted to show simulation results instead of measured data. Wijk and van Selow (1999) address the issue of visualizing recurring 24-hour patterns in non-spatial datasets over the course of a year. The recurring patterns are detected automatically and displayed alongside time series plots using a calendar-inspired graphical tool.

Little previous work can be found in the building simulation field on what we call *multiscale visualization*: the visualization of both recurring and anomalous patterns that involve multiple length scales and time scales.

2.3. Related Work in Other Fields

Formal studies suggest that animations produce better learning and pattern recognition than static images (Höffler and Leutner 2007), and in this work we apply this principle to simulated occupant motion. One of many challenges associated with the multiscale visualization of simulation results is that, if there are movements that are clear when animated over short periods of simulated time, these movements may become incoherent when longer time periods are animated. To address this problem, we turn to non-photorealistic rendering, a sub-discipline of computer graphics which investigates various stylistic techniques to emphasize or communicate certain aspects of a scene or scenario. Of particular interest is the work of Joshi et al. (2005) exploring the application of illustration techniques from traditional hand-drawn images to convey motion. Whereas Joshi et al. focus on movements extracted from CFD results, Haller et al. (2004) present similar stylized computer animation techniques in the context of computer games. The specific techniques considered in Joshi et al. (2005) and Haller et al. (2004) include *speedlines* (called *motion lines* in Haller), *flow ribbons* (only in Joshi), and *strobe images* (referred to as *opacity modulation* in Joshi, *multiple images* in Haller). We explain these techniques in Section 4 applied to occupant simulation results.

A key visualization challenge is the fact that important events in a simulation may be overlooked if presented while a viewer's attention is focused on more prominent animated objects. For example, the opening of a window may be a key event with a long-lasting effect on a building's indoor climate and energy requirements. However, because the act of opening of a window is associated with a small region of space and a short period of time, it may go completely unnoticed. The obvious strategy for addressing this problem is to alter animations in a way that draws attention to certain parts of the screen at appropriate points in time. This is one of several goals of *attention cueing* as described in de Koning et al. (2009), a review of related experiments in the field of cognitive psychology. One example of an attention cue is a glowing effect used in an animated organizational graph showing how a company changes structure over time (Khan et al., 2009a).

A third challenge is that, when visualizing multiscale data in animations or interactive software, users can become disoriented in space (McCrae et al. 2009), in time, or in both dimensions. To reduce disorientation in the perception of time, inspiration can be drawn from various graphical tools in the field of human computer interaction (HCI). Dachselt et al. (2008) propose a timeline graphic in which the user can zoom in or out to reveal representations of time periods of dramatically different durations. Khan et al. (2009b) present a clock-inspired graphic with concentric circles that show how much progress has been made through a presentation, and how much time has elapsed.

3. PROTOTYPE SIMULATION AND RESULTS

We developed a prototype occupant simulation in order to obtain a set of 3D simulation results suitable for exploring a variety of visualization techniques. The model will be explained in detail elsewhere, though here we give a brief overview. The simulation represents the hypothetical two-storey hotel shown in Figure 1, which features 11 guest rooms, a restaurant, a kitchen, an office, circulation areas, and storage space. At any given time the hotel may be occupied by about 10 employees and two or three dozen guests. The simulation tracks the position of each simulated occupant. It also predicts air temperatures, which vary smoothly over the interior of the hotel and change gradually over time.

Each activity and action of each simulated occupant is determined randomly according to probabilities influenced by their role, the time of day, and comfort level. Most of the probability distributions were chosen arbitrarily to produce realistic behavior adequate for visualization research. Guests tend to visit the restaurant during meal times, for example, whereas employees tend to exit the hotel in the evening. While energy and water consumption were modeled, the only form of occupant-building interaction with a visible effect was the manual opening of windows in response to high indoor temperatures. One run covering 18 hours of simulated time provided a time series of each occupant's changing coordinates and activities. These results were used to produce roughly 40 experimental videos exploring the visualization techniques presented in the following sections.

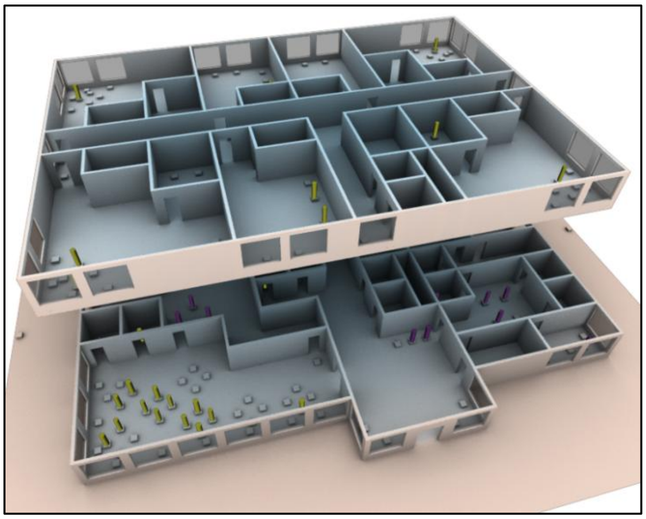

Figure 1. A snapshot of the simulation results. The cylinders represent hotel guests (yellow) and employees (purple). The color applied to the floors and walls indicate cool (blue) and warm (red) temperatures.

4. PERCEPTION OF OCCUPANT MOVEMENT

Previous work in the domain of building evacuation modeling has concentrated on visualizing relatively short time periods. Occupants move slowly and their movement is clearly communicated. However, to make valid inferences in the domain of energy use and comfort modeling, multiple time scales need to be considered, such as hours, days, and weeks. For example, if an occupant walks into a room and immediately closes a window, that might indicate a greater degree of discomfort than if the occupant remains in the room for hours and only then closes the window. To draw such contextual understanding from long simulations in a reasonable amount of time, it is necessary to speed up the playback of the simulation results. However, large *speedup* factors can make motion appear incoherent as objects may move significant distances between animation frames.

Consider a case of trying to compress a long simulation into a 10 second animation played at 24 frames per second (fps). If we want to watch the results of a 1-hour simulation, we would need a speedup factor of 360. Each animation frame would represent 15 seconds of simulated time, in the span of which an occupant can cover around 21 meters (assuming average waking speed of 1.4 meters per second). With simulated occupants covering such distances between frames, motion would appear incoherent. Refer to Figure 2 for an illustration of this problem, where two consecutive frames, images (a) and (b), show simulation results that were speeded up 360 times. Looking at the two frames, one might conclude that occupant A in the first frame is the same person as occupant C in next frame, and that occupant B is the same as occupant D. However, in the image (c) of Figure 2, speedlines are used clarify the movement of the occupants, showing that while occupant A indeed moved to location C, occupant B went down the hallway and a third occupant walked into location D.

The addition of *speedlines* to a scene is an art technique often used to convey motion in print illustration. Unlike particle traces, which are commonly used in engineering applications, speedline curves do not precisely adhere to simulation-generated paths. Instead they are smoothed to more clearly communicate the essence of a motion, ignoring small details and noise in the actual path. Another stylistic depiction is an X-ray effect to communicate hidden activity, achieved by showing speedlines with a decreased opacity when obstructed by the building geometry. See Figure 2(c) and Figure 3(b) for illustrations of this effect.

We vary line thickness along a speedline to help convey the direction of motion and the time since the occupant was present at a location. Thicker lines indicate recent occupant positions while thinner lines indicate old positions. The maximum line thickness is set to a constant and then scaled to indicate the age associated with the position. In particular, the *scale factor*, *s*, at a given position along the curve is a function of Δt_{age}, the duration of animation time since an occupant was present at that position.

$$s = 1 - \frac{\Delta t_{\text{age}}}{\Delta t_{\text{fade}}}, \text{where } 0 \le \Delta t_{\text{age}} \le \Delta t_{\text{fade}}$$

The input parameter Δt_{fade} represents the animation time required for speedlines to fade away. This parameter stays constant throughout the visualization. For example, with a value of 0.25 seconds for Δt_{fade}, the speedline will disappear after 6 frames of 24 fps animation, after the occupant stops moving. The speedline length increases as Δt_{fade} increases.

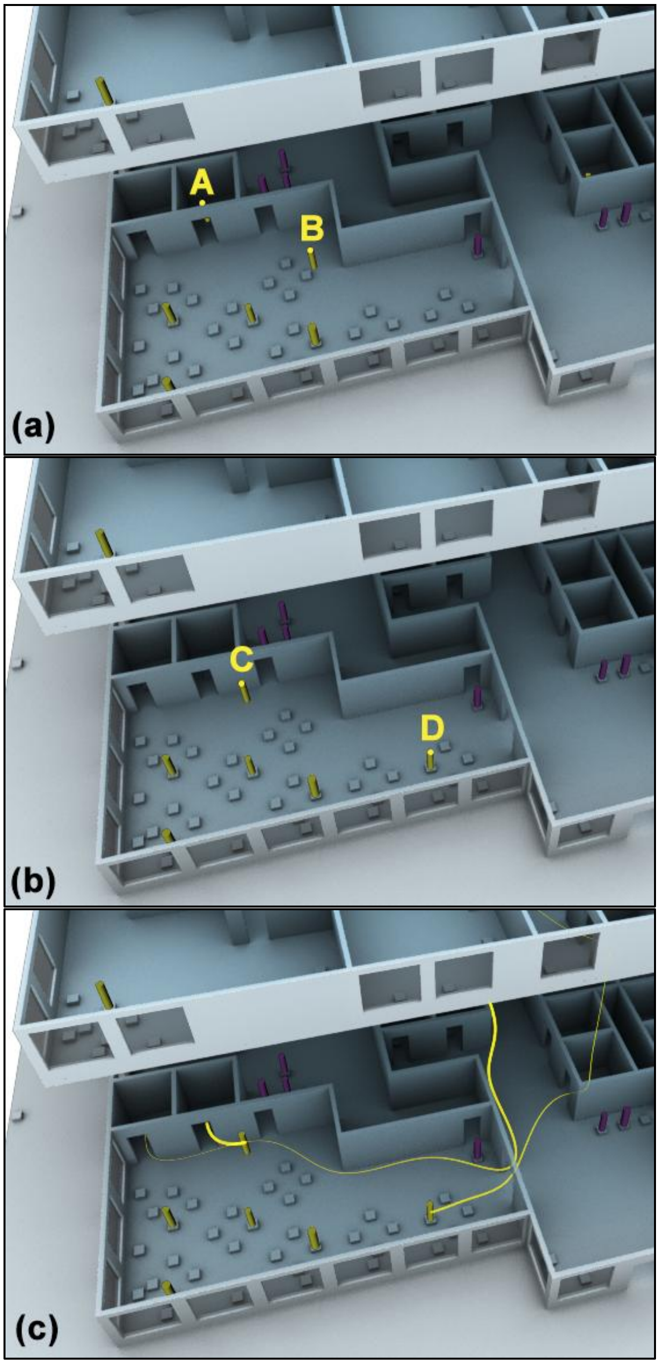

Figure 2. Two consecutive frames (a) and (b) at 360x speedup; image (c) includes speedlines to resolve the ambiguity in occupant movement.

Figure 3 demonstrates the effect of using a small Δt_{fade} in image (a), where the speedline only indicates that the occupant entered the room. The larger Δt_{fade} in (b) also communicates the origin of the trip. Note that increasing the speedup factor also increases the length of the speedlines, as occupants cover greater distances between frames. In Figure 6, a speedup of 3600 results in extremely long speedlines. Each animation frame represents 150 seconds of the simulation, enough time for occupants to move as much as 210 meters.

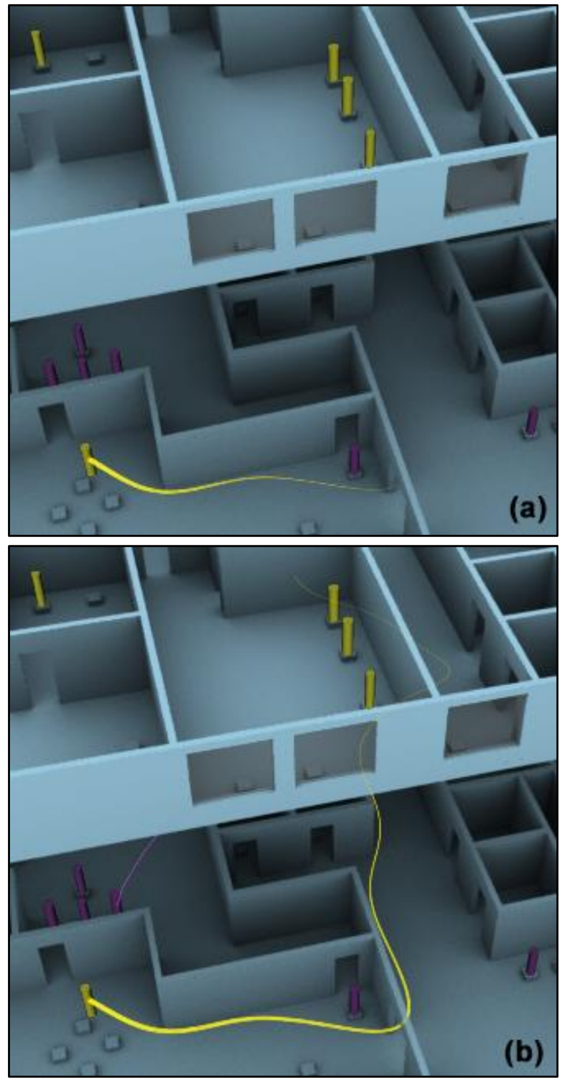

Figure 3. Speedlines, (a) short *speedline*, and (b) longer *speedline*.

The main trade off in picking the right value for Δt_{fade} is that large values will retain movement-related information longer, but increase the visual complexity of the animation. The long speedlines associated with large Δt_{fade} emphasize frequently travelled paths, potentially aiding designers in their understanding of circulations patterns. However, the longer the speedlines, the more likely they are to blend with one another, which partly conceals the motion of individual occupants. This blending of speedlines is likely to occur for complex scenarios animated with high speedup factors.

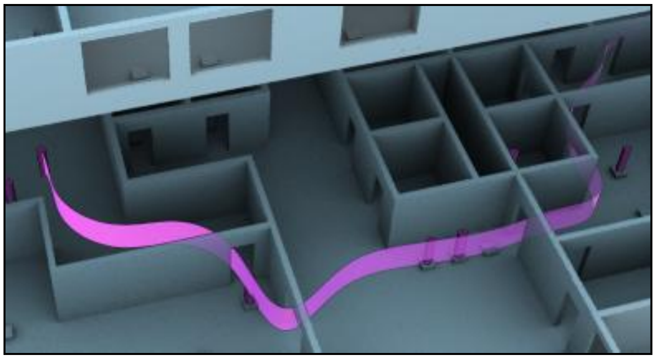

Figure 4. An example of a ribbon tracking an occupant.

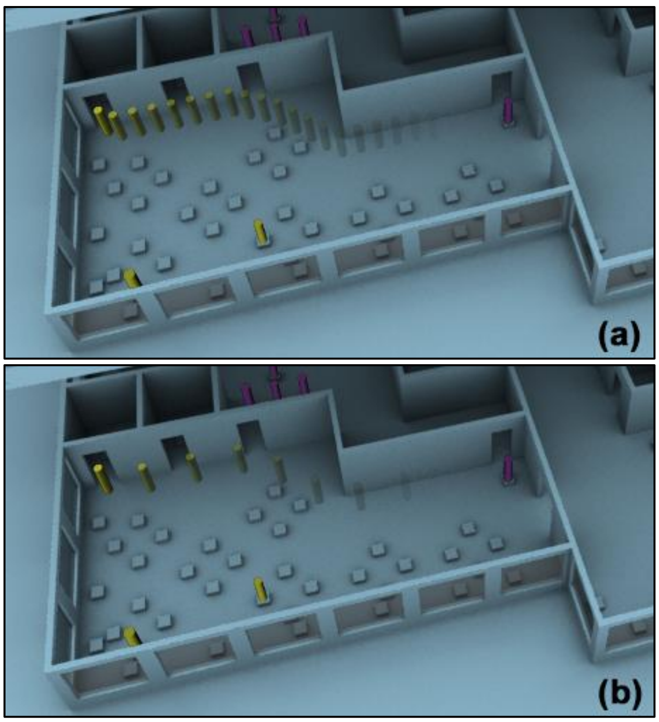

Figure 5. High density (a) and low density (b) strobe visualization.

We have extended our implementation of speedlines to flow ribbons (Joshi et al. 2005), as shown in Figure 4. A *flow ribbon* can be described as the surface between two speedlines curves, one trailing the bottom of an occupant and the other trailing the top. Instead of varying thickness, surface opacity is modulated in the same fashion. Unlike speedlines, ribbons convey the relative size of an object, as well as any change in its orientation. In our case only occupant positions were modeled, but if we were to track their orientations as well, ribbons would help communicate events such as falling or lying down. Flow ribbons exhibit a strong visual relationship with 3D geometry, making it clear when occupants move through doorways.

Another artistic motion depiction we explore is *strobe images*. To achieve a strobe effect an object is drawn several times in a given frame with different opacities, where more transparent versions indicate older positions. As shown in Figure 5, we experimented with the effect using different density levels. Strobe images can reveal subtle details of occupant interactions with the building when used with a more anthropomorphic occupant representation rather than the cylindrical geometry shown in our animations. With a strobed anthropomorphic occupant, activities such as opening windows, switching lights, or pressing elevator buttons would be apparent since the actual occupant shape and action would be represented in each image. For example, it would be easy to distinguish whether a person standing near a window is actually trying to open it, or whether they have simply stopped to enjoy the view. A disadvantage of strobe images is that they may lead viewers to overestimate the total number of simulated occupants.

5. ATTENTION TO KEY EVENTS

Visualizations that overlay multiple types of information have the potential to reveal patterns involving a diverse set of simulated elements and effects. By simultaneously observing temperature, occupant movement, and window states, a designer may become aware of a situation where a poorly designed room leads to overheating, which induces occupants to leave a window open, resulting in increased overnight heating load. There is, however, a drawback to displaying large amounts of information: a key event, such as the opening or closing of a window, may be completely overlooked. The problem is expressed in de Koning et al. (2009) as follows:

> *…it is not surprising that learners often have difficulties in focusing their attention on essential information in an animation, as objects that have high perceptual salience due to their movements easily distract them. This might especially hinder learning in situations where the thematically relevant aspects are not the most salient in an animation.*

In our visualizations of the hotel and its occupants, we observe that the opening of windows can be difficult to spot. While speedlines, flow ribbons, and strobe images seem beneficial for the perception of movement, they attract the viewer's attention and in all likelihood increase the chances of window manipulations going unnoticed. We therefore experimented with a glowing effect, similar to the treatment of organizational structure changes in Khan et al. (2009a), to cue attention to a window slightly before it is opened. The effect is shown in Figure 6. The green glow is quite salient even in comparison with the long speedlines required to clarify movement over a long time scale.

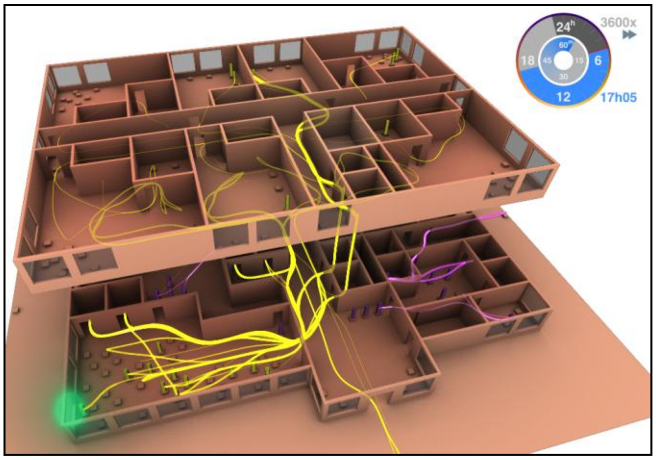

Figure 6. A glowing effect draws the viewer's attention to a window being opened in the hotel restaurant.

Note that the red color in Figure 6 indicates warm late afternoon temperatures. By contrast, the shades of blue in Section 4 reflect an earlier time of day. We are coloring building geometry based on temperature data as previously done by Hailemariam et al. (2010), with the difference that the temperature data is simulated, not measured.

The use of a short-lived glowing effect is an example of cueing in animation applied to simulation results. Previous work reviewed in de Koning et al. (2009) inspires a number of ideas for future research in this area. Another way to emphasize a key event is to slow down the animation while the event is unfolding, then speed it back up once the event has passed. An important lesson from past work is that even if cueing is successful at directing the viewer's attention, it will not necessarily result in better understanding of what the animation represents. User studies evaluating a wide range of new and existing visualization techniques could provide valuable insights into how designers observe and interpret patterns found in detailed simulations.

6. PERCEPTION OF TIME

Time plays a crucial role in simulation, and it is therefore essential that visualizations clearly communicate the temporal context associated with each event. This temporal context applies to time as represented in the simulations, as well as the progress one has made through the animation. We have designed a custom clock widget, illustrated in the top right corner of Figure 6 and in more detail in Figure 7, that consolidates time-related information pertaining to simulated events and the visualization itself.

To help the viewer associate simulated events with their associated periods of simulation time, the inner ring of the clock shows the minutes of the current hour, and the outer ring shows the hours of the day. A narrow band of color surrounds the outer ring with dark purple near midnight and light yellow near noon. This provides a non-numerical indication of the time of day to supplement the clock labels.

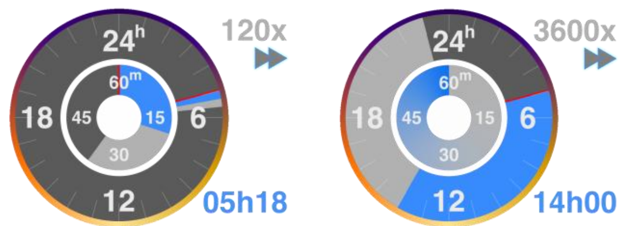

Figure 7. Clock widget at speedup rates of 120x (left) and 3600x (right).

The start time of the simulation is shown with a red line. To show the total time period covered by the simulation, sections of the rings are colored light gray while inactive periods are colored dark gray. The elapsed duration of the simulation is shown using a blue radial progress bar, which gradually fills the light gray area. If the simulation exceeds an hour, the inner radial progress bar fades away rather than forming a solid color slice, since the simulation duration is outside the range of 60 minutes. To precisely communicate the current time of the simulation, a numerical time value of both hours and minutes is shown in the bottom right corner of the widget in a blue color matching the color of the progress bar inside the clock's rings. Since the time scale is hard to perceive with large speedup factors, a numerical value of the factor is shown in the top right corner of the widget with a fast-forward symbol below it. To minimize distraction from the primary visualization, the clock is placed in the corner where it is somewhat unobtrusive yet easily referenced. The widget clearly indicates when an animation loops, as the blue sections reset to light gray.

While currently our widget only supports minutes and hours, in the future we plan to generalize it to work on larger scales such as days, weeks, months, etc. This direction of generalization motivated the decision to place the hour ring of the clock on the outside of the minute ring, in contrast with traditional analog clocks where the hour hand is shorter than the minute hand. The principle behind placing hours on the outside is to keep transitions in spatial and temporal representations consistent: one zooms out on a projection of a 3D model to reveal larger spatial scales; one should "zoom out" on the clock widget to reveal additional rings for days of the week, weeks of the month, months of the year, and larger time scales as needed.

7. CONCLUSION

To help designers understand increasingly complex occupant simulation results, we have explored the use of several visualization techniques inspired by previous work in non-photorealistic rendering, cognitive psychology, and human-computer interaction. The results of a prototype simulation were animated at different speeds, demonstrating how speedlines, flow ribbons, strobe images and attention cues can clarify the movement of occupants and emphasize their interactions with a building. To situate events in both simulation and animation time, we designed a scalable, novel clock widget. We have demonstrated how several multiscale visualization challenges can be addressed for simulated patterns unfolding over seconds, minutes, and hours. Future research is needed to extend these techniques to days, seasons, and years. Also, user studies are necessary to quantitatively evaluate the strengths and weaknesses of each technique. This paper represents an early step towards enhancing sustainable design tools with automatically generated 3D visualizations effective for discovering subtle details in simulation results featuring multiple time scales.

References

BOURGEOIS, D. 2005. Detailed Occupancy Prediction, Occupancy-Sensing Control and Advanced Behavioural Modelling within Whole-Building Energy Simulation, Ph.D. Thesis, l'Université Laval, Canada.

DACHSELT, R., FRISCH, M. AND WEILAND, M. 2008. FacetZoom: A Continuous Multi-Scale Widget for Navigating Hierarchical Metadata. Proceedings of the SIGCHI Conference, Florence, Italy, 4 pages.

DE KONING, B.B., TABBERS H.K., RIKERS, R.M.J.P. AND PAAS, F. 2009. Towards a Framework for Attention Cueing in Instructional Animations: Guildines for Research and Design. Education Psychology Review, vol. 21, 28 pages.

GOLDSTEIN, R., TESSIER, A. & KHAN, A. 2010. Customizing the Behavior of Interacting Occupants using Personas. Proceedings of the SimBuild IBPSA-USA Conference, New York, NY, USA, 8 pages.

GOLDSTEIN, R., TESSIER, A. AND KHAN, A. 2011. Space Layout in Occupant Behavior Simulation. Proceedings of the International IBPSA Conference, Sydney, Australia, 8 pages.

HAILEMARIAM, E., GLUECK, M., ATTAR, R., TESSIER, A., MCCRAE, J. AND KHAN, A. 2010. Toward a Unified Representation System of Performance-Related Data. Proceedings of the eSim IBPSA-Canada Conference, Winnipeg, Canada, 8 pages.

HALDI, F. 2013. A Probabilistic Model to Predict Building Occupants' Diversity Towards their Interactions with the Building Envelope, Proceedings of the International IBPSA Conference, Chambery, France, 8 pages.

HALLER, M., HANL, C. AND DIEPHUIS, J. 2004. Non-photorealistic rendering techniques for motion in computer games. Computers in Entertainment, 2(4), 10 pages.

HOES, P., HENSEN, J.L.M., LOOMANS, M.G.L.C., DE VRIES, B. AND BOURGEOIS, D. 2009. User behavior in whole building simulation. Energy and Buildings, 41(3), 8 pages.

HÖFFLER, T AND LEUTNER, D 2007. Instructional animation versus static pictures: A meta-analysis. Learning and Instruction, 17(6), 722-738.

JOSHI, A. AND RHEINGANS, P. 2005. Illustration-inspired techniques for visualizing time-varying data. Proceedings of the IEEE Visualization Conference, Minneapolis, MN, USA, 8 pages.

KHAN, A., MATEJKA, J., EASTERBROOK, S. 2009a. The Role of Visualization in the Naturalization of Remote Software Immigrants. Proceedings of the Software Engineering Conference, Kaiserslautern, Germany, 6 pages.

KHAN, A., MATEJKA, J., FITZMAURICE, G., KURTENBACH, G., BURTNYKA, N. AND BUXTON, B. 2009b. Toward the Digital Design Studio: Large Display Explorations. Human–Computer Interaction, 24(1), 39 pages.

MCCRAE, J., MORDATCH, I., GLUECK, M. AND KHAN, A. 2009. Multiscale 3D Navigation. Proceedings of the ACM Symposium on Interactive 3D Graphics, 8 pages.

MCLOUGHLIN T., LARAMEE R. S., PEIKERT R., POST F. H. AND CHEN M. 2010. Over Two Decades of Integration-Based, Geometric Flow Visualization. Computer Graphics Forum, 29(6), 23 pages.

NARAHARA, T. 2007. The Space Re-Actor: walking a synthetic man through architectural space, Master's Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA.

PAGE, J. 2007. Simulating Occupant Presence and Behaviour in Buildings, Ph.D. Thesis, École Polytechnique Fédérale de Lausanne, Switzerland.

RASSIA, S. 2008. The analysis of the role of office space architectural design on occupant physical activity. Proceedings of the International Passive and Low Energy Architecture (PLEA) Conference, University College Dublin, Ireland, 6 pages.

TABAK, V. 2008. User Simulation of Space Utilisation: System for Office Building Usage Simulation, Ph.D. Thesis, Technische Universiteit Eindhoven, Netherlands.

URBAN, B., GOMEZ, C. 2013. A Case for Thermostat User Models. Proceedings of the International IBPSA Conference, Chambery, France, 8 pages.

VAN WIJK, J. J. AND VAN SELOW, E. R 1999. Cluster and Calendar based Visualization of Time Series Data. Proceedings of the IEEE Symposium on Information Visualization, 5 page.