Early-Stage Egress Simulation for Process-Driven Buildings

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Abstract. Many complex buildings such as hospitals, airports and industrial facilities are process-driven, meaning that their design is conceived around the daily work routines of the staff, usually captured using business processes (e.g. by using flowcharts or Business Process Modeling Notation). The main idea and contribution of our approach is to leverage such a static process model in order to facilitate a dynamic egress simulation. In detail, we perform a process simulation until a specified time t is reached. As result, we get the typical location of the working staff as well as occupancy of all areas of the building, which we then feed into an agent-based egress simulation. As result, we can obtain the evacuation performance at time t under consideration of the building's process model, i.e. different usage scenarios throughout the day. This hybrid approach between process simulation and pedestrian simulation is especially suited for early stages of building design, when different spatial configurations and process variants are under consideration. In this context, the approach is just one part of many lines of architectonical reasoning, covering foremost the problem of accessibility and adjacency by means of pedestrian simulation.

Keywords: Process Simulation, Pedestrian Dynamics, Functional Design

1 Introduction

The planning of process-driven buildings is occupied foremost with the production of a spatial design that facilitates the daily work routines of the building users. Especially in the early phases of the design project, architects and organization planners work in close cooperation to achieve this goal:

- **Organization planners** define the operational model of the organization, which takes the form of a hierarchy of business processes (processes and sub-processes), an organizational schema containing the responsibilities for each process (i.e. process roles), and, ultimately, a definition of staffing needs arising out of the process model.
- **Architects** define a spatial configuration that satisfies the organizational requirements, most prominently: the business processes. In this context, multiple variants of a preliminary design (also called architectonical schema) are being evaluated,

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the key criterion being the adjacency of areas which exhibit a high degree of cooperation (as described by the process model).

In previous work[1], business process simulation (BPS) has been used to superimpose processes over the preliminary design, in order to constrain the spatial concept so that it fulfills the process model and at the same time visualize work routines of the staff. This paper extends on these concepts, by introducing a (dynamic) egress simulation that is based on the state of the aforementioned (static) process simulation at a time t. More specifically,

1. The state of the process simulation at time t gives the usage of each space.
2. An egress simulation takes this usage and computes the pedestrian flow to the nearest exits.
3. The recorded density and evacuation times can then be visualized and subsequently used to get an insight into bottlenecks occurring because of the spatial arrangement and expected occupation of the building at time t, at quite an early stage.

The inner mechanics of this hybrid simulation are detailed in Section 3. Apart from the actual communication between BPS and ABS, we also contribute a look at the required synchronization constructs used (see Section 3.1, "Communication between process simulation and agent simulation").

2 Related Work

Our approach is based on connecting a Business Process Simulation (BPS) to an Agent-Based Simulation (ABS). We are aware of many approaches following this hybrid approach (e.g. [2,3]), but none seems to be specifically focused on the early planning of process-driven buildings, which is central to our work. What makes this context special is that it requires statements about circulation and adjacency of the preliminary design[4] on a qualitative (rather than quantitative) level. Simulation as means for such insights, especially concerning dynamic aspects of movement and occupancy remains an area where previous work is extremely scarce; one example in this respect concerns user simulation of space utilisation[5], using the (three-dimensional) circulation network within the planned building as basis. In contrast to our work, the emphasis here is on office buildings and user behaviour (rather than planned processes), which can be used as basis for design optimization when simulating physical movement and subsequent space utilization[6,7]. A similar approach focusing on sensitivity of a circulation network towards congestion and blockage[8] forms the basis of the evacuation simulation presented herein.

3 Inner Mechanics of the Hybrid Egress Simulation

3.1 Preparing the process model

Our simulation is based on Microsoft Visio, a modeling platform commonly used by organization planners for process modeling. Classically, the notation employed for this task has been based on flowcharts, in which nodes of the flow graph are annotated with additional data, either through data contained within a shape (see Fig. 1a), activity nodes with additional visual elements to hold metadata (Fig. 1b) or comments (Fig. 1c).

In our case, this metadata is important because it has to contain the physical location within the preliminary design (i.e. "where" an activity is taking place). We used unique room stamps such as "1E01" which had to be manually attributed, and later mapped to locations via a table.

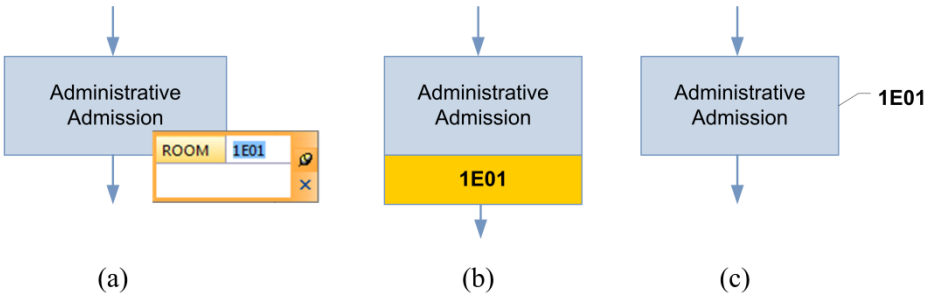


Fig. 1. Metadata for nodes within a process (a) as additional shape data, (b) attached graphical element or (c) comment.

It is also important to note that we employ a special style of process modeling in which each process represents one role - e.g. patient, staff, etc.; while this is not true for the common case - but almost always done in the context of planning of process-driven buildings. The reason for this lies in the communication between architects and building organization planners, which happens mostly by tracing these processes on preliminary floor-plans, one at a time.

3.2 Invoking the simulations from the modeling platform

Using Visio's scripting support, we first export the process flowcharts in a custom format (see Fig.2a) for use in our own (external) process simulation (see Fig.2b). In parallel to the process simulation, an agent-based simulation (ABS) which computes pedestrian flow (Fig.2c) is also started. Process simulation and agent-based simulation (Fig.2d) work synchronized, with messages being passed bidirectionally: Upon reaching a specified time t, the process simulation issues such a simulation request, passing all active processes (instance names, room stamp associated with currently executing nodes). The agent simulation generates an agent for each supplied process instance, and starts the egress simulation, employing whatever physical movement algorithm to

move all agents to the nearest exit. In our concrete case, we use the cell-based movement model given by Blue and Adler[9]. As result of a model run, the ABS records simulated densities and the Required Safe Egress Time (RSET) for that instance t. Trivially, the outlined procedure can be repeated for a whole day, giving planners a clear picture over evacuation performance of their process-driven building at a single glance.

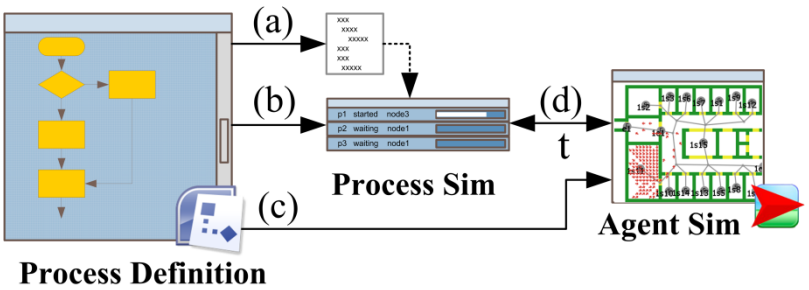


Fig. 2. Interaction between different parts of proposed approach. (a) Export of processes from Visio as input to (b) process simulation. (c) Agent simulation is opened in parallel and receives (d) simulation requests at time t from process simulation.

3.3 Communication between process simulation and agent simulation

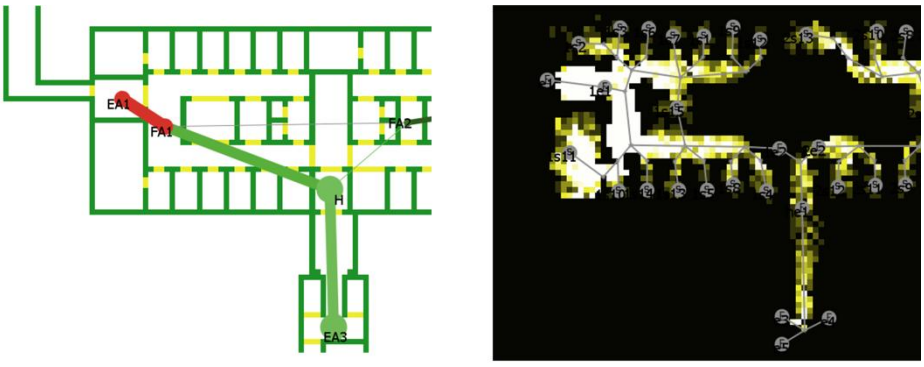
Our process simulation is an adaptation of a widely used business process engine[10], for the sake of showcasing our approach. The same goes for our agent simulation, which is based on the popular NetLogo ABS platform[11]. Both simulations act as servers and clients, performing bidirectional data exchange over sockets using a fixed protocol.

Communication between BPS and ABS requires some synchronization construct, since these simulation types differ in their time bases (future event list versus simulation in seconds). In simplest approach, which we have undertaken, BPS and ABS both progress in seconds. For each time step, the BPS executes processes scheduled at that instance. Once time t is reached, it issues the command to begin simulating to the ABS, passing the active processes and their respective process states (including the attributed room stamp of the current node) for subsequent instantiation of agents. On the side of the ABS, the passed room stamps are used for obtaining a location for a new agent within the design, which (in our case) is composed of a cell-based floor plan and a superimposed graph-based route network that is used in conjunction with the Blue-Adler physical movement model to simulate the passage from one space to the other. The results (Densities per cell, RSET) can be communicated back, e.g. for use in a report covering the span of a day.

4 Outcome for the Design Process

As Rittel is often quoted, design is a “wicked” problem[12] that is hard to describe without reference to some solution. The presented evacuation analysis represents a step into this direction, albeit in a qualitative manner:

- The variation of the computed RSET throughout the day can be taken as overall measure of complexity/congestive tendency of the proposed design. Alternative designs can be considered when comparing two such RSET curves at equal sampling points.
- The congestive tendency within the design can be visualized by (1.) assignment of all spaces to a functional area (2.) counting the passages between different functional spaces and (3.) visualization of these as a bubble diagram (see Fig 3a) with weighted line and node thicknesses. Because the flow is measured for a whole day, the variability in throughput can be furthermore color coded to depict areas of high sensitivity to congestion.
- Space utilization can be counted and visualized as well, by means of a color scale (see Fig. 3b). Furthermore, as in the previous case, areas of high variability in usage throughout the day could be highlighted, since these are probable candidates for multi-functional use. Depicting space utilization visually is very important for ensuring proper separation between private/public areas. Another possibility for further work is the explicit depiction of types of process participants (e.g. patient, staff), in order to spot possible flow crossings which are unwanted (e.g. because of hygienic or again privacy considerations).



(a) (b)

Fig. 3. Depicting results. (a) Bubble diagram with throughput (b) Space utilization for a single timestep

5 Summary

We have proposed a hybrid approach linking static process simulation to dynamic egress simulation, in order to visualize bottlenecks and accessibility problems for the design process-driven buildings, based on occupancy provided by the process model. In contrast to existing egress simulations, our efforts are targeted at early stages of design and act as qualitative means rather than giving quantitative statements. The choice of process simulation and pedestrian algorithm is up to the implementers - the authors use an own process simulation linked to a Blue-Adler model.

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