Nov 2nd, 2:30 PM - 2:45 PM

More-Space – A Simulation Tool for University Room Management

Nicole Nagele-Wild
Vienna University of Technology

Š. Emrich
Vienna University of Technology

S. Tauböck
Vienna University of Technology

Felix Breitenecker
Vienna University of Technology

Niki Popper
dwh Simulation Services

See next page for additional authors

Presenter Information
Nicole Nagele-Wild, Š. Emrich, S. Tauböck, Felix Breitenecker, Niki Popper, and D. Wiegand

More-Space – A Simulation Tool for University Room Management

Nicole Nagele-Wild[1], Š. Emrich[1,2], S. Tauböck[1], F. Breitenecker[1], N. Popper[2], D. Wiegand[3]
[1] Vienna University of Technology, Inst. of Analysis and Scientific Computing
[2] dwh Simulation Services
[3] Vienna Univ. of Technology, Inst. of Urban Design and Landscape Architecture

Abstract. As proposed in various studies, educational facilities hold a high potential yield for improvement of room utilization. The goal of the project "MoreSpace" at Vienna University of Technology (TU Vienna) was to develop a hybrid modeling approach which helps to increase the efficiency of the university's space utilization. Besides coupling of Discrete Event Simulation (DEVS), Agent-based (AB) methods and Cellular Automata (CA), successful deployment of such a model requires a thorough integration within the peripheral system. Which in turn leads to preconditions that have to be met, (e.g. by input-data, visualization of results, dissemination, etc.). This paper covers the methods applied for analyses of the model and the peripheral system, which enable model integration. For this is necessary to also focus on the psycho-social layer of the institution, as it is this layer that often leads to rejection of otherwise "good" solutions by the people within institutions. The paper further describes a deployment matrix which puts the simulations-models mode of operation (i.e. one time utilization for consulting, recurrent and frequent utilization) into context with met preconditions and the required depth of system integration. This allows it to estimate whether a model can be deployed as intended or not; with alternatives being either a transformation of the system, reformulation of the question(s) towards the model or - in the worst case - abortion of the deployment process. In the latter case the value of the deployment matrix lies within an early judgment of the situation saving resources that would have been spend otherwise. In addition it is possible to use these for developing alternative solutions in support of the intentional goals.

Keywords: Mobile data traffic, Wi-Fi offload, data optimization

1 Introduction

Over the last few years "sustainability" has become a frequently used catch-word – not without controversy, as it is often used misleadingly or in a subjective manner. Nevertheless nowadays it is commonly accepted that the lifestyle (especially that of developed countries' populations) needs to be more responsible in order to achieve the goal of a balanced ecological footprint.
Looking at this challenge it becomes clear that such an ambiguous objective cannot be achieved only through scientific improvement and utilization of "new technologies". For example does a newest generation-car consume less fuel and produce less greenhouse gases, but still it is more efficient to use an already built car instead of trading it for one that needs yet to be produced: Increasing efficiency of the already existing has to play an essential part in the struggle towards a sustainable lifestyle. To the authors' knowledge efficient utilization of buildings – spare highly specialized industrial buildings (e.g. real estate in production & logistics, airports, etc.) – has not been subject of optimization-approaches based on modeling and simulation until now. This is quite surprising seeing that especially for large-scale buildings and building-complexes (for instance educational institutions or office blocks) an efficient management can significantly increase the utilization of given (room-) resources, as shown in [1]. The present paper focuses on improving space management in order to increase space utilization (lecture room utilization). As it has the power to drastically in- but also decrease efficiency, proper management is crucial. The complexity of defining good space management lies within the problem definition – in most cases it is unfeasible if not impossible to test and evaluate management strategies

in vivo. A key to the task of finding efficient management strategies lies within simulation, as it overcomes this problem. A simulation-based approach for evaluation – which subsequently allows improvement – of space management strategies, is presented in this paper.

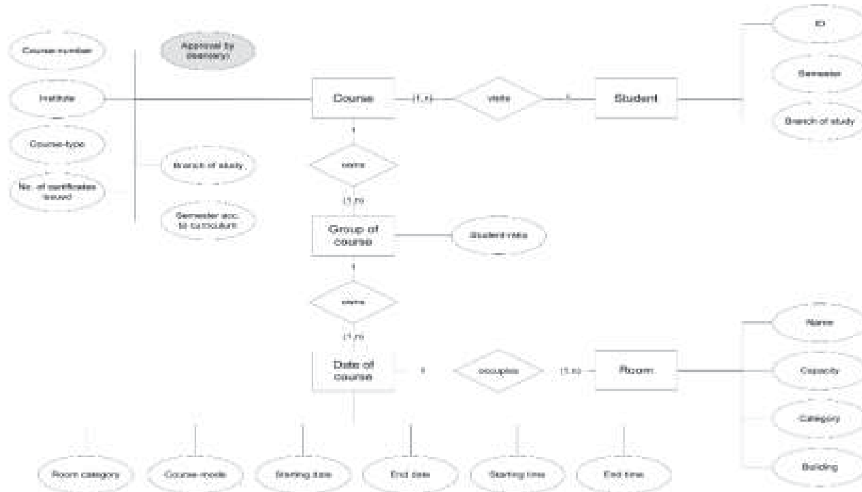

Fig. 1. Entity-Relationship Diagram (ERD) of the model input-data.

2 Problem Setting

A model for simulation of various (lecture) room-management strategies of course needs to incorporate the control strategies that are to be simulated. Further the type of use of the space has to be represented by the model. This directly leads to questions such as:

- Who are the users?
- (How) Are they affecting utilization?
- How do space (lecture rooms) requirements look like?
- Which rooms are available?

Some of these questions can be represented by (input) data while others are to be captured by the model-structure.

In order to combine the control strategies as well as user behavior a hybrid model was set up. The core-model consists of a Discrete EVent Simulation (DEVS)-framework (implemented in Enterprise Dynamics) with agent-based elements in order to incorporate the individual (student-) behavior. For this an appropriate mapping, in order to transfer the server-resource-definition onto the given problem of space allocation, had to be found. Walking times are either presented via a look-up table with average times between two locations or via a sub-model, based on Cellular Automata (CA). The CA within this sub-model are again extended by agent-based methods to capture the individual (student) behavior. Last but not least Business Process Modeling (BPM) is utilized to firstly analyze and secondly coordinate the interrelationship of the system's stake holders. Within the course of the project it was found that the used technique (IBM's Business Process Modeling Notation) did not satisfy the demands and was thus modified.

3 Utilizing and Adapting the Methods

As stated above the methods applied within this simulation project had to be modified or extended prior to their combination within the hybrid model. In this section the methods are described and the modifications explained briefly.

3.1 Discrete Event Simulation (DEVS)

The roots of discrete event simulation can be traced back to the middle of the last century [2]. Over last decades DEVS has become a standard tool for the analysis and improvement/optimization of resource-utilization in various areas. Among those are such broad fields as for example supply chain management, production and logistics but also specialized areas as hospital management. DEVS' theoretical basis is the Entity-Resource- or Entity-Flow-Concept. Entities are searching their way through processes to the according resources, while this way is controlled or influenced by events. E.g. patients inside an emergency department resemble the entities that are routed through diagnostic and treatment processes to the respective resources (X-ray, doctor diagnosing fracture, etc.). The way of the patients is depending on events (for example a finished diagnoses or nascent resources). Within facility management or more generally within management of the resource "room" – in terms of spaces inside a building – DEVS have not been utilized until now, as explained in section 1. Thus a proper definition or mapping of the DEVS-concept had to be found: while resources can be identified unequivocally with rooms, several projections are possible for the entities. Room is generally reserved/booked for a certain demand. This demand can be identified in two ways: as groups of people that want to carry out certain work or tasks or as tasks/work that needs room – and is associated with specific persons. For the present model the first approach has been chosen. This required to break down the systems onto the individual users, as the groups – which carry out work (i.e. lectures) within the rooms – are changing. Individuals can be "members" of several groups, which again can be "acting" at the same time. In this case the respective individual can of course not participate in both groups and consequently – in the worst case scenario – a group could represent a null set and thus not require space at all! From this it follows, that although the entities of the DEVS-concept are represented by the groups, individuals are playing a key-role (at TU Vienna roughly 20.000 individual students need to be considered). These individuals are implemented as a combination of DEVS-atom and agent-based (AB) element. In such a way each of them can be assigned an individual controller logic - the "schedule". Thus these agents or atoms are acting in response to events (lectures) but also goal-oriented as they decide how to proceed when conflicts arise – a feature that adds much to the dynamic system behavior as well as it brings it closer to reality. The next obstacle that needed to be overcome was the adaption of the model to a changing system. The implementation of DEVS models usually takes place using simulation environments (Enterprise Dynamics in the present case) that offer model-libraries and support drag-and-drop model creation, which offers a certain amount of flexibility and ease of use. Still it becomes hard to manually create a model consisting of several thousand entities (lectures taking place) and several hundred resources (rooms). Even more as those are subject to change – e.g. changing building plans during construction, blocked rooms due to repair or maintenance, changing curricula, etc. The complexity of the necessary input-data is displayed by the Entity-Relationship Diagram (ERD) in figure 1. To conquer this obstacle a module for database-driven model generation has been developed (see [3]). It enables the model to be created automatically and fast out of (room-)databases. Subsequently the model becomes highly flexible and can represent virtually any room structure – given the necessary database. Another advantage of this structure is the ability to modify rooms themselves. If necessary two adjacent rooms (with the appropriate infrastructure) can be combined to create a bigger one and vice versa.

3.2 Cellular Automata (CA)

To model walking times between (lecture) rooms cellular automata have been used. CA are – as DEVS is – a fairly old modeling technique with origins reaching back to the middle of the past century. Its modeling base lies, as one could expect by the name, within individual cells. This base is independent of the various different types of cellular automata: the states of their cells are subject to change, depending on the influence of neighboring cells and transition rules. Further they are very simple to describe (and thus to implement) but are still capable of reproducing very complex systems with unpredictable behavior (see [4]). Cellular automata are especially suitable for modeling walking times as their structure bases on a spatial grid that can be easily translated into any spatial context - though a problem lies within the individualism of the entities that are to be simulated. This is again overcome by an agent-based extension of the cellular automata. With this approach each individual can be clearly identified and thus passed forth and back between the DEVS-model and the CA-model in order to compute its walking times (see [5] for a detailed description of the model and [6] for further information on the combination of CA and AB-methods).

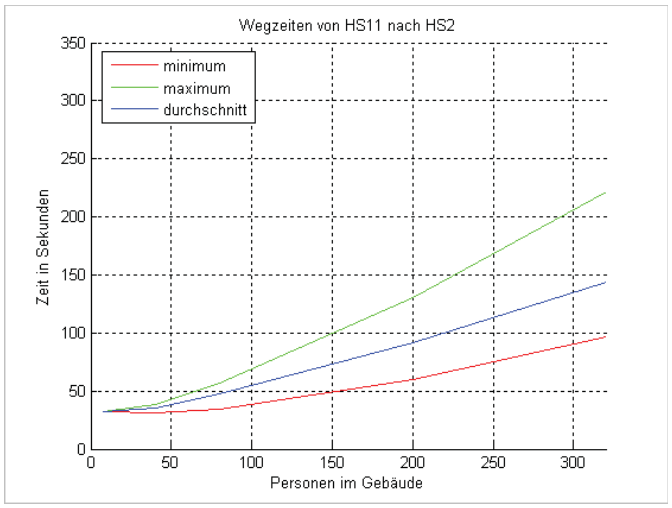

Fig. 26. Monte Carlo simulation of walking times (y-axis, time in seconds) vs. number of moving agents (x-axis) with average time (blue), maximal (green) and minimal (red) time consumed.

As previously mentioned the walking times can be either simulated on the fly for higher precision or approximated by lookup-tables. As real-time simulation of walking times is consuming a high amount of processing power when utilized for the whole university campus, the CA is used in order to compute sound approximations for the walking times. Figure 2 shows the correlation between walking times and the number of simultaneously moving agents. In order to increase the computational efficiency the university campus is not depicted by a single CA – which would inevitably consist of many "white areas" which do not need modeling. Instead the buildings are broken down to hallways and corridors which are mapped onto individual CA. This does not only result in slender automata but also allows to parallelize their computation.

3.3 Business Process Modeling Notation (BPMN)

The BPMN was standardized by the Business Process Management Initiative (BPMI) and released in 2004. Its primary goal was to provide a notation that is readily understandable by all people involved within a business process – from the business analysts to the technical developers. This is achieved by an appealing graphical notation, which basic flow elements are extremely easy to understand and grasp (from [7], [8]).

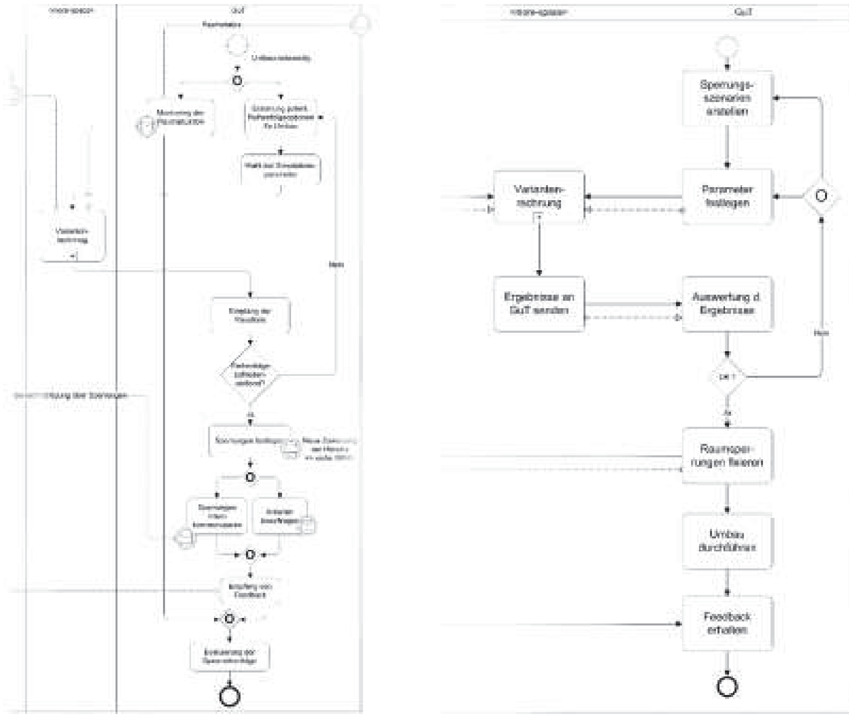

Fig. 37. Comparison of original (left) and modified (right) version of a BMP (view on same section of business process).

For interdisciplinary projects the use of such techniques is almost indispensable. Business Process Modeling (BPM) is especially valuable at the starting phase of project when a common language needs to be established: With only a short period of vocational adjustment all team-members can understand and use it. Despite BPMN's benefits it was found in the course of the present project that it has some shortcomings as well. The regulations and specifications of the notation are increasing the complexity of the depicted systems beyond the level necessary for this project. Thus the notation was modified to better suit the specific needs and subsequently does not equate with IBM's BPMN-specification. Figure 3 does visualize the effect of the modification undertaken. It is a side-by-side comparison of the original (left) and modified (right) notation, both displaying the corresponding section of the same business process. While the conventional notation requires special symbols for every action and decision these have been omitted for the modified version to further increase readability by simplification. A flow-item for the handover of data has been introduced to achieve an even better grasp. Utilization of BPM made it possible to model the business processes in use for the room-to-event-assignment (allocation of lecture rooms for courses) at Vienna University of Technology for the first time ever. Based on this system-analysis new processes and associated preconditions for a more efficient space management have been developed.

3.4 Coupling of the Model

While for technicians it is tempting to focus on the (DEVS-) core of the simulation-model in order to produce results, only the coupling of all previously described elements allows to fully exploit the available potential.

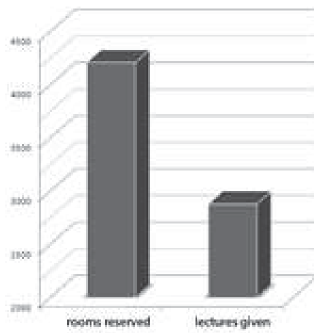

Fig. 48. Comparison of room reservation (left) and lectures held (right) in hours

The development of business processes made it possible not only to find a huge gap between the amount of held lectures and the time for which rooms have been reserved (see fig. 4) but also the reason for this: a bug within the reservation system. Through lack of control and coordination between departments this bug was not noticed before, as course-data did not undergo any (central) supervision but was taken as valid by all stakeholders.

3.5 Deployment Matrix

Tab. 1: The deployment matrix as a guideline to the feasibility of modes of operation.

		Recurrence	
Preconditions	**frequent**	**infrequent**	**non-recurring**
all met	possible	possible	possible
some met	not possible without transformation	eventually with workaround	likely, based on workaround
none met	not possible without transformation	not possible without transformation	unlikely. transformation not reasonable & workaround costly

Model preconditions are deduced from the implementation and thus from its features. Hence, as a good model itself cannot be reduced any further, so cannot its requirements and thus its preconditions. Business process models and entity relationship models can be used to check whether:

- the preconditions of the model are met,
- the business process of the peripheral system is adequate, and
- if the necessary (input) data can be provided by the stakeholders (identified via stakeholder analysis and in the BPM).

If the requirements cannot be fulfilled, the model cannot be deployed as intended. Instead of aborting the project, in such a case it is also possible to pursue two alternative strategies: Reformulation of the question towards the model in order to abate preconditions or adaption of the system's business processes. Adequate reformulation of questions, leading to a less demanding model means that the original questions will remain unanswered — which will often be undesirable. If on the other hand changing the business processes is too costly (especially in relation to the expected gain of the simulation project), a compromise between the two options might become interesting. As previously noticed, the depth of integration is connected to the model's levels of detail and its requirements, which hints that changing the mode of operation might open the option for model deployment. Naturally such a change influences the quality and/or amount of information derived from the model. The converse argument holds as well: different simulation goals can be achieved through differing levels of system integration.

2 Simulation Results

2.1 Units for Quality-Measurement

The goodness of a certain assignment of events (lectures) to rooms greatly depends on subjective criteria. A senior lecturer might favor one which grants him to use "his" or "her" traditional room while students might appreciate short walking distances between consecutive lectures. As it is impossible to generate solutions that oblige every bodies wishes "hard", objective measurement units need to be found.

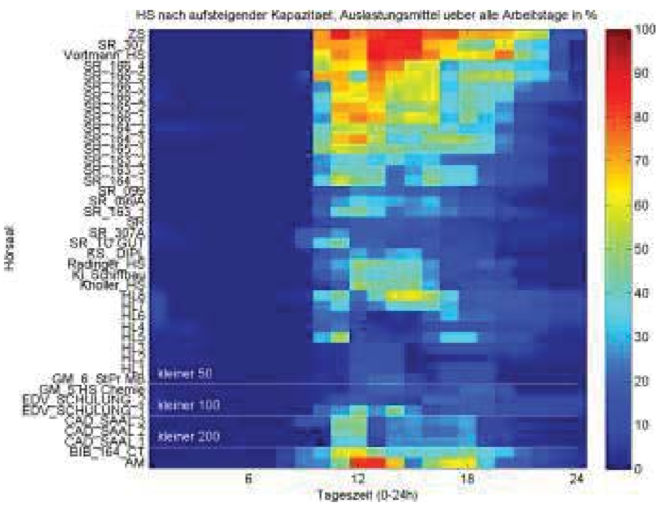

Fig. 59. Utilization (x-axis) of lecture rooms (y-axis) during the day, semester average (lecture rooms decreasingly sorted by increasing capacity).

In the present case the number of *erroneous entries*, the *room utilization* and *room usage* were chosen to be the main evaluation units. An *erroneous entry* denotes one room request (for a single, specific date and time slot of an event) that cannot be met. The *room utilization* is defined as the fraction of (core) time during which a room is used by events and the *room usage* expresses the extent to which the capacity of a room is exhausted (the fraction of people within the room, compared to the capacity of it).

2.2 Control through Expert-Decisions

Because of the complex structure of authority – at least at TU Vienna – and the huge search space the control of the room-allocation-procedure is subject to expert-decisions, with the results of the simulation runs being an auxiliary tool.
Due to the amount of data produced during simulation runs (round about 20.000 single events need to be coordinated during each semester at TU Vienna) the results need to be filtered and preprocessed (semi-automated) in order to be useful to the experts in charge. This is done in several steps.
Via a graphical user interface (GUI) database-internal (based on Access-reports) data-processing routines can be triggered that produce rudimental diagrams. In a second step the data is processed by external tools (currently MATLAB, will be replaced by license-free code) in order to fabricate more sophisticated visualizations. Figure 5 represents such a diagram in which the room utilization is depicted. Based on the information obtained by these two steps manual investigations are conducted in directions promising an improvement of the room-assignment control.

2.3 The Influence of Space Management

Based on currently implemented space management strategies and input-data from previous semesters first conclusions can be drawn. Opposite to the “felt” situation of insufficient room resources the actual system does – by far – not reach its limits. The diagram in fig. 6 does show the utilization of rooms-categories. Even the categories “auditorium” (left) and “seminar room” (2nd from left), which are used by far more frequently than the rest, are not close to the practically achievable limit of 60% to 80%. Insufficient room could generally be identified as either temporal collisions during peak times or as reservations of rooms without authorizing event/lecture. Hence the solution is as simple as a re-scheduling of some courses and introduction of the previously mentioned improved business processes. But at the same time it becomes apparent that the currently implemented space management combinations (25 totaling: 5 booking-rules and 5 priorizations) are not differentiated enough and need to be refined, which can be seen in figure 7.
The diagram shows the number of unsatisfied room requests (on basis of single and specific dates of events) for 15 scenarios that have been tested. Although a certain influence, especially of the chosen rule-set L123 (blue), L23 (green) and L3 (orange), can be observed, the differences are not dramatic. The rule-set defines the priorization order of room-assignment to events. The three basic options are:

- rooms are assigned to events if the capacity fits perfectly,
- rooms are assigned within the building of the organizing department
- rooms are assigned as soon a category- and capacity-requirement is met.

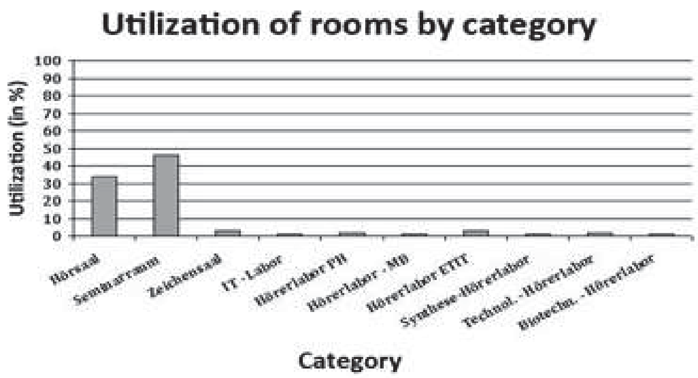

Fig. 6. Utilization of rooms by category (representative scenario)

3 Conclusion and Outlook

Based on the results and insights gained so far a positive course might be expected for the project. Until the present point the data used was only “historic” (from previous semesters) hence the upcoming interface-development for simulation with current data is likely to bring results interesting for the experts controlling the room-allocation procedure. The presented results from section 2 showed that the created model still needs refinement (which is already planned). The control-capabilities for the space management with the improved model are to be tested subsequently. As explained in section 3.4 the project strongly benefited from the introduction of BPM for the analysis of the system and interrelations between stakeholders. With many IT-projects failing because the developed software does not blend into the surrounding system, the use of BPM should be considered to improve this situation. BPM is also helpful when defining (business) processes to identify bottlenecks and define preconditions.

While the model is currently being tested in order to aid the control of space management it could be extended in the future in order to evaluate building design prior to construction. In such a way the control-mechanism could be improved and adjusted together with the building plans according to the intended building' usage.

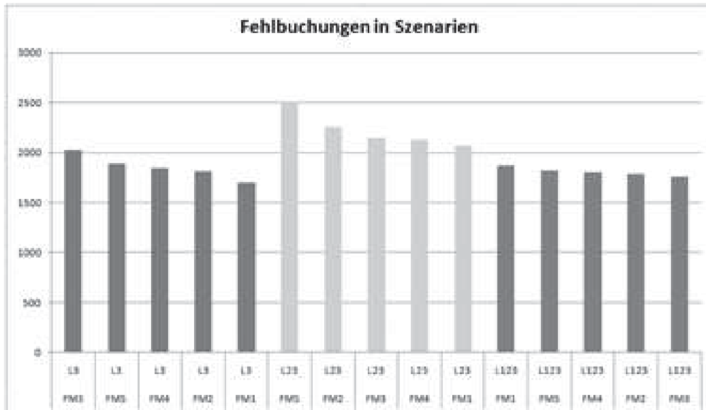

Fig. 7. Unsatisfied room requests of 15 simulation runs with differing space management strategies.

Generally speaking a building with a more efficient space utilization can house more units of use. On the one hand this leads to reduced costs per unit, as the fixed costs for rental, heating, maintenance, etc. are divided on more usage. On the other hand it benefits the environment, as it results in a reduced ecological footprint per unit. Another potential area of research is the adaption of the CA model. With proper modifications it could be used to control pedestrian flow through buildings. For example routing blind people or those unfamiliar with the building complex from one point to another with respect to the current state (e.g. avoiding overcrowded hallways, get around broken elevators) or even for intelligent partitioning and guidance of people during evacuation.

References

1. Wiegand, D., Mebes, P., Pichler, V.: Event based simulations: Enabling improved development planning and partnership. In: Schrenk, M., Popovich, V.V., Benedikt, J. (eds.): REAL CORP 007: To Plan Is Not Enough. Strategies, Concepts, Plans, Projects and their Successful Implementation in Urban, Regional and Real Estate Development, CORP, Wien/Schwechat, Austria (2007) 17–23
2. Nance, R. E.: A history of discrete event simulation programming languages. ACM SIGPLAN Noteces, 28, No. 3 (1993) 149–175
3. Tauböck, S. M.: Integration of Agent Based Modelling in DEVS for Utilisation Analysis: The MoreSpace Project at TU Vienna. TU Vienna, Vienna (2010)
4. Wolf-Gladrow, D.: Lattice-Gas Cellular Automata and Lattice Boltzmann Models. Springer, Berlin, Germany (2000)
5. Bruckner, M.: Modellierung der Fußgängerdynamik im universitären Betrieb mit Hilfe von Zellulären Automaten in der Programmiersprache JAVA. TU Vienna, Vienna (2009)
6. Emrich, Š., Breitenecker, F., Zauner, G., Popper, N.: Simulation of influenza epidemics with a hybrid model - combining cellular automata and agent based features. In V. Luzar-Stiffler, Hljuz Dobric, V., Bekic, Z. (eds.): Proceedings of the ITI 2008 30th Int. Conf. on Information Technology Interfaces, Zagreb, Croatia, SRCE University Computing Centre University of Zagreb (2008) 709–714
7. White, S. A.: Introduction to BPMN. http://www.bpmi.org/downloads/Introduction_to_BPMN89.pdf, 2004.
8. Wolter, C., Schaad, A.: Modelling of task-based authorization constraints in BPMN. In: Proceedings of 5th Intl. Conference, Springer, Berlin Heidelberg, Deutschland (2007) 64–79