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Designing a BIM-based serious game for fire safety evacuation simulations

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ABSTRACT

This paper presents results of the first phase of the research project "Serious Human Rescue Game" at Technische Universität Darmstadt. It presents a new serious gaming approach based on Building Information Modeling (BIM) for the exploration of the effect of building condition on human behavior during the evacuation process. In reality it is impossible to conduct rescue tests in burning buildings to study the human behavior. Therefore, the current methods of data-collecting for existing evacuation simulation models have limitations regarding the individual human factors. To overcome these limitations the research hypothesis is that the human behavior can be explored with a serious computer game: The decisions of a person during the game should be comparable to decisions during an extreme situation in the real world. To verify this hypothesis, this paper introduces a serious gaming approach for analyzing the human behavior in extreme situations. To implement a serious game, developers generally make use of 3D-modeling software to generate the game content. After this, the game logic needs to be added to the content with special software development kits for computer games. Every new game scenario has to be built manually from scratch. This is time-consuming and a great share of modeling work needs to be executed twice (e.g., 3D-modeling), at first by the architect for the parametric building model and the second time by the game designer for the 3D-game content. The key idea of the presented approach is to use the capabilities of BIM together with engineering simulations (fire, smoke) to build realistic serious game scenarios in a new and efficient way. This paper presents the first phase results of the research project mainly focusing on the conceptual design of the serious game prototype. The validation concept is also presented. The inter-operability between building information modeling applications and serious gaming platforms should allow different stakeholders to simulate building-related scenarios in a new, interactive and efficient way.

1. Introduction

During the last decade, the significance of emergency management in public infrastructures has increased due to changed security conditions worldwide, which has led to the necessity of computer-aided emergency assessment process for extreme situations. Nearly every day natural as well as fire disasters or terrorist attacks are reported in the news and show the importance of making the built environment as secure as possible. Especially, in the field of Fire Safety Engineering (FSE) engineers have to face many challenges. The population growth leads to urbanization and results in mega-cities with densely populated areas. In such areas a wide spread of building types and ages are present: high-rise buildings, architectural and historical monuments, airports, railway stations and shopping malls – only to address a few – standing side by side. The decreasing number of building permits, counted by the German Federal Statistical Office (DESTATIS) [1] for both, new buildings and refurbishments, indicates that in Germany the building stock is slowly being renovated. For this reason, the average building age is getting increasingly old. Moreover, statistics in Germany show that the number of deaths due to fire and smoke is re-increasing since 2007 [1]. It is difficult to say whether there is a correlation between building age and death rate in case of building fire. However, according to interviews we conducted with fire fighters in the context of this research, most of these people died in older residential buildings. This fact underlines the assumption that there is deferred maintenance, particularly for fire protection, which prevents the safety level of existing buildings from being as high as it could be according to the state of the art. The challenge for civil engineers is no more to build new buildings; whereas more and more existing buildings are being refurbished and redeveloped. This new work focus is characterized by uncertainty, complexity and is conflict-ridden. During the fire safety design process, fire safety engineers have to consider a lot of prescriptive codes. This often results in the use of unnecessarily large safety factors and overly expensive costs to the building owner in case of refurbishments. For this reason, necessary refurbishments, especially to improve the safety level, run the risk of being deferred.

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The next section gives a brief introduction to an alternative to prescriptive codes: the performance-based fire protection design.

1.1. Performance-based fire protection design

Today, fire safety engineers have an alternative to the use of prescriptive codes. Since a few years ago, a new way to reach fire safety design decisions is just being established: the performance-based approach. This process started at the beginning of the last decade driven by the ISO [2]. Many countries follow this strategy in redesigning their fire safety code systems with two parallel tracks to include performance-based as well as prescriptive regulations. In the German fire safety community a lot of work is still in progress in this particular field. With applying the performance-based approach for fire protection design decisions the focus is rather on demonstrating the safe performance of a building as a whole than meeting the detailed code requirements (e.g., height and area limits, fire-resistance ratings, egress, separations). For this purpose, it is important to understand the performance of the building and the behavior of endangered people in this building under fire exposure. During a fire event structural systems have to meet different functions (e.g., load-bearing and barrier). The load-bearing function on the one hand is important to avoid the collapse of the structural system, on the other hand the barrier function has to prevent the expansion of fire and smoke. To provide safe and smoke-free escape routes both functions must be fulfilled by the structural system. Johann et al. [3] describe an approach to integrate performance-based fire protection into the design process for structural framing systems. Johann et al. mention that it is necessary to integrate theoretical knowledge, empirical information, analytical capability and technology that has been developed by fire safety engineers into the design process. To carry out these tasks fire safety engineers make use of computer models and simulations for the description of expected spread of fire and smoke, the safety evacuation and the analysis of the overall safe performance of a building [4]. Especially, to estimate the behavior of endangered people is an essential purpose for analyzing the safety evacuation of a building, since the protection of human life is the primary aim of the performance-based approach. Beyond the people's behavior and the corresponding human factors, the rescue mission is influenced by other factors like alarm systems, building elements and the spread of fire and smoke. In particular to map the human factors onto computer models is a challenge, because each person's singular behavior is based on individual decisions and parameters and is not deterministic like the spread of fire and smoke, which can be modeled and simulated based on natural principles. So, according to Santos and Aguirre [5], for an evacuation simulation, three analytical dimensions need to be considered: Firstly, the built environment (physical location), secondly, the management of this environment (signage, escape routes), and thirdly, social psychological and social organizational characteristics of the occupants. Tavares [6] mentioned that an evacuation simulation model must consider four interactions: occupants–structure; occupants–occupants; occupants–fire (in case of fire events) and fire–structure (for this purpose, a fire model should be used). The next section gives a brief overview of evacuation simulation with the focus on data-collecting efforts to model the human behavior.

1.2. Evacuation simulation

As mentioned in Section 1.1, considering the human factors is a big challenge for fire safety engineers in the performance-based fire protection design process. There are different reviews of existing evacuation models published in the last years [5,7] showing that every modeling approach has its strengths and weaknesses. The next section focuses on the question of how to collect data for the human behavior models. Most current evacuation simulation models follow the agent-based approach. An agent is a software instance which represents a virtual person during the simulation runtime. To find out the human factors scientists use different methods like interviews, (online) questionnaires, map exercises, experimentation or the analysis of past emergency situations using interviews of survivors or CCTV recordings. The focus of the data-collecting efforts in the past was more to find out clinical mobility parameters, for example, motion speed or required space of the people according to their age or gender. These parameters were then used for statistical assumptions to describe the agent's movement during the evacuation simulation. Nowadays, fire safety engineers are in agreement that these parameters are insufficient to describe the complex process of decision making of people during evacuations and to cover all dimensions of an evacuation simulation as mentioned in the previous section. These human factors must be considered in a more holistic manner, especially regarding the interaction with the actual building status quo.

The results from the Society of Fire Protection Engineers Survey (SFPE) [8], for example, show that people often come to unexpected decisions if they are asked what they would do if they were exposed to a threatening fire. The SFPE survey concludes that some kind of behavior like fighting the fire or trying to gather belongings often results in delays before people decide to evacuate. So these delays could lead to dangerous situations, because fire and smoke spread very quickly through a building. Such behaviors are based on individual decisions and it is not quite clear why some people decide this way while others decide to evacuate immediately. Furthermore, the SFPE survey mentions that human factors, which are based on individual decisions and risk assessment, should be considered by fire safety engineers to reach better design decisions.

During the research work, several software systems for evacuation simulation were evaluated. As a result, the state of the art evacuation simulation software buildingEXODUS [9], developed by the Fire-Safety Engineering Group (FSEG) at the University Greenwich, UK, was chosen for further consideration. BuildingEXODUS makes use of agent-based modeling and according to the developers it incorporates a wide range of sociological attributes and characteristics. These human factors data are collected over years as a result of different research activities in this field. Different methods, which were documented by various publications, were used for data acquisition. One example is an online survey published by Kinsey et al. [10]. In this survey, the scientists of the FSEG wanted to find out the key factors, which influence human behavior during an evacuation of a high rise building regarding the question to select the lift or the stairways. The Survey participants were presented with a series of hypothetical situations and asked how they would behave. Further within the UK High-Rise Evacuation Evaluation Database (HEED) study [11], scientists make use of interviews to collect and classify the experiences and behaviors of WTC evacuees in a database. The aim of other research methods is to improve the underlying agent-based model of buildingEXODUS by integrating wayfinding processes [12], the influence of signage [13] or to introduce a prototype emotion model into an agent based circulation simulation [14]. It is important to take all of this into account in agent-based simulations, because in reality human behavior in complex environments is dynamic and fixed plans are often changed and adjusted according to the persons' individual interpretation of the emergent conditions. For the visualization of the simulation results of buildingEXODUS the add-on vrEXODUS is available. vrEXODUS can be used to generate 3D visualizations of the evacuation simulations in virtual reality.