Designing interactive virtual environments for focus groups in the field of fire safety

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1. Extended Abstract

Introduction.

Integrating fire safety engineering into digital building design faces challenges, including the balance between prescriptive requirements and performance-based verification methods confronting all participants in the planning processes with difficult decision-making processes. Stakeholders often overlook the impact of fire safety on design, treating it as a constraint rather than a valuable design variable [Maluk et al. (2017)]. Through performance-based methods, fire safety engineers can enforce and argumentatively replace prescriptive requirements. Challenges such as the comprehensibility of possible fire safety solutions for the authorities approving a building project, the earlier involvement of fire safety in the design process, as well as the question of a competence model to clarify areas of responsibility are perennial topics of discussion. Research has shown that in order to generate benefits for all parties involved, fire safety should be integrated as a design element earlier in the planning process [Buchanan and Abu (2016), Athanasopoulou et al. (2023)]. Some advocate fire safety engineers the same importance as architects within holistic project management tasks [Magnusson et al. (1995)]. Further, they state that the respective stakeholder's relationship remains uncertain [Maluk et al. (2017)] or in need of further research [Magnusson et al. (1995), Athanasopoulou et al. (2023)]. Conversations with fire safety planners, responsible for preparing and gaining approval for fire safety certificates, indicate that machine-readable prescriptive requirements improve integrity in digital building processes like Building Information Modelling [Fitkau and Hartmann, 2021]. However, the neglect of deviations and the creative work involved in performance-based methods leads to uneconomical solutions and increased redundancy in fulfilling fire safety requirements. This restricts the freedom of planners and builders, while augmenting the responsibilities of operators and approving authorities [Zehfuß et al., 2020].

Research has shown that digital tools support integrated collaboration [Fischer et al. (2017)], but communication difficulties remain. Serious games like the "dilemma cube" [Castaño et al. (2017)] and the "Expansive Hospital Game" [van Amstel et al. (2016)] address this. Other research includes simulation environments for specific cases like asphalt paving [Vasenev et al. (2016)] and human behaviour in disaster scenarios [Schatz and Rüppel (2015)].

We would like our research to play a part in generating explicit evidence of whether a truly integrated approach to fire safety can therefore establish relationships to improve the interaction between fire safety practitioners and leaders in other sectors of the construction industry, and to that end we also question the appropriateness of redundancy in meeting fire safety requirements. We believe that this requires using expansive learning methods in an environment where participants can argue in a non-judgmental and transparent manner while still being able to receive quick feedback on an individual level. To ensure this kind of environment, we choose to bring together the necessary stakeholders in form of focus groups. In order to assist this method of qualitative data acquisition, we present a high-level conceptual model of an ontology-based serious game. It specifically targets the following areas of the planning process: a) earlier involvement of the fire safety engineer, b) mapping of both prescriptive requirements and the possibilities of performance-based verification methods, c) expansive learning to better understand and engage other stakeholders.

Concept of Research.
According to [Bjelland et al. (2017)], each design project involves unique socio-technical systems that exhibit characteristics as a whole, rather than the sum of their parts. To effectively map complex phenomena like an integrated decision-making approach in fire safety, employing systems thinking becomes crucial for comprehending the interrelationships among elements in a specific environment. In our concept of a serious game, which aims to facilitate learning of novel processes, we incorporate [Engeström and Sannino (2010)]'s 'expansive learning' concept, which involves creating new knowledge and practices for emerging activities, such as truly integrating fire safety into building design. The game serves two purposes: a) through it, players are allowed to experience and explore new planning processes and b) providing visibility and assessment of player actions and learning success. To ensure the game's robustness, we integrate the concept of 'stealth assessment' into its design process. Stealth assessment involves evaluating learners during gameplay to gain insights into learning processes and gain immediate feedback to identify areas of difficulty for learners. [Shute et al. (2022)]
The game follows the Triadic Game Design (TGD) framework by [Harteveld, C. (2011)], which we combine with the concept of stealth assessment by [Shute et al. (2022)] for a robust assessment strategy. The Triadic Game Design framework is an approach to find one representation of reality that can then be logically translated into an interactive environment. To facilitate feedback-based and expansive learning goals, involving stakeholders (architects, structural engineers, fire safety planner, insurers, regulators, etc.) through focus groups would follow [Cyr, J. (2016)]'s recommendation to address transparency issues and provide clear presentation guidelines. This aims to foster interaction and collect emerging skills.
In overall summary, our proposed method focuses on emergency operations related to building data in the planning phase, supported by a legal text-based ontology. It consists of two steps: (1) developing a combined methodology of the TGD framework and 'stealth assessment' to establish interrelations between emergency planning, structural fire safety, and diverse player roles, and (2) applying this methodology to design a serious game.

Novel Framework Approach.
We aim to integrate the TDG framework [Harteveld, C. (2011)] with stealth assessment [Shulte et al. (2022)] to create a comprehensive approach that incorporates fire safety into the building design process. In consequence it should result in a robust serious game that enhances fire safety awareness and decision-making for planners. The TDG framework consists of the "world of reality," "world of meaning," and "world of play". The reality component involves gathering information and developing a domain-specific model. The meaning component focuses on proposing values based on the model, while the game component involves designing a game concept or prototype. Stealth assessment by [Shute et al. (2022)] is a ten-step iterative process summarized as follows: (1) develop a competency model, (2) embed stealth assessment in the game or digital learning environment, (3) identify relevant gameplay actions as evidence, (4) create new tasks if needed, (5) establish a task-competency mapping, (6) determine scoring categories, (7) pilot test, (8) adjust parameters, (9) validate the assessment, and (10) use player competency states for adaptive learning support. Our proposed novel framework is the following:

Reality Category:

a. Define the Competency Model (Player Component) for players, which encompasses fire safety knowledge, skills, and attributes necessary for building design. This involves understanding relevant building code to develop competencies like knowledge of fire resistance ratings, and familiarity with fire suppression systems.

b. Select or Design the Game (Game Component) that engages and allow all players to experience and understand the implications of their design choices on fire safety. For instance, develop an interactive environment where players can modify building layouts, select materials, and place fire safety equipment such as fire extinguishers and smoke detectors.

Meaning Category:

a. Identify Relevant Gameplay Actions/Indicators (Game Component) as evidence of fire safety competencies, such as using fire-resistant materials and optimizing escape routes. For instance, track the percentage of fire-resistant materials, and assess accessibility and coverage of fire safety equipment in the environment.

b. Design Tasks and Scoring Rules (Game Component) that evaluate players design choices. For example, task players with optimizing building layouts to maximize distance between fire-prone areas and exits. Score their choices based on criteria like proximity of fire-rated walls and the presence of sprinkler systems.

Game Category:

a. Establish Connections in the Q-matrix (Game Component) linking game tasks to fire safety competencies. For instance, connect tasks like choosing fire-rated materials to the competency of understanding fire resistance ratings for building materials.

b. Integrate Adaptive Learning Support (Player Component) to provide targeted feedback to enhance understanding of fire safety principles and improve design decisions. For example, suggest fire-resistant materials, or provide in-game guidance based on identified competency gaps.

c. Consider Cultural and Social Context (World Component) and adapt the game to incorporate region-specific fire safety regulations, local evacuation practices, and community-specific fire prevention measures.

d. Validate and Iterate (Player Component, Game Component, World Component) the integrated approach through playtesting, expert feedback, and external measures continuously. Refine the game, competency model, and learning supports based on evaluation insights by conducting usability testing with architects and engineers to gather feedback on usability and effectiveness in promoting fire safety awareness.

Conceptual Model of a Serious Game.

Since floor planning is a critical aspect of building design that requires careful consideration and collaboration among all stakeholders, it can enhance skills such as comprehensive perspective, optimized space utilization, technical feasibility, and risk mitigation. By tackling floor planning within a serious game context, one can harness the collective expertise, insights, and perspectives of various professionals within a collaborative setting, leading to well-informed decisions and optimized designs.

In alignment, we present a high-level conceptual model for a game combining strategy, collaboration, and competition, focusing on fire safety in architectural design. Players assume roles as architects, engineers, and fire safety experts, creating safe buildings while achieving personal objective goals. This gamified approach serves as an expansive learning tool, offering insights into fire safety in architectural design. The game represents the building under construction, featuring a grid-based playfield, building components, objective cards, and an event deck introduce variability. Players strategically place building components to expand the building, considering both functionality and fire safety. Collaboration, event resolution rotation, and the option to reveal objectives enhance strategic decision-making. The game balances collaboration and competition as players work together to meet fire safety requirements while pursuing their personal objectives. Negotiation, alliances, and critical thinking play vital roles in achieving success. Regarding the fire safety requirements, we use a supporting ontology called PrevFiS [Fitkau and Hartmann, (2021)], an ontology of preventive structural fire safety. It has been developed to make rule-based building code data accessible to fire safety engineers. Enriched with data it can serve as a knowledge base for the upcoming focus groups. The conceptual model supports further development, playtesting, and refinement. It combines entertainment with education, simulating design complexities and fire safety requirements. The game fosters strategic thinking, collaboration, and adherence to safety standards. Future work involves refining the game based on this model to create an immersive and impactful experience.

Implications.

This paper presents a high-level conceptual model of an ontology-based serious game that targets earlier involvement of fire safety engineers, maps prescriptive requirements and performance-based verification methods, and facilitates expansive learning and stakeholder engagement. Through the development of a novel game design approach, the researchers aim to enhance the robustness of the game experience. However, it is anticipated that the innovative framework will undergo adaptations as a prototype of the game is developed based on the presented conceptual model. The high-level concept model is expected to gain more intricacy as the competency model is refined. The competency model should then be validated in collaboration with fire safety experts through e.g., semi-structured interviews and existing research. The prototyping phase will follow an iterative process, involving a carefully selected research team with relevant expertise, to ensure technical usability and enable subsequent steps such as conducting focus groups with key stakeholders in the construction industry. Considering that stealth assessment is tailored for supporting digital serious games [Shute et al., 2022], we envision the prototype to present an interactive virtual environment. In the future, the authors hope that this prototype could serve as a solid foundation for the application of artificial intelligence, particularly in relation to the elements encompassing the 'meaning category' within our novel framework. Further benefits are expected from this approach to investigate the representability of ontologies with simultaneous use of a strong visualization in the form of an interactive environment: First, statements about the future of ontology domains and whether they have the ability to be incorporated into an interactive environment and second, whether the approach of using gaming in focus groups is really worthwhile in the field of the AEC-domain fire safety by achieving better results.

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