IDRiM(2023) 13 (2) **ISSN: 2185-8322**
DOI10.5595/001c. 91474

Journal of Integrated Disaster Risk Management

Original paper

Fire Safety in Smart Cities in Hungary with Regard to Urban Planning

Gergő Érces[1] * Sándor Rácz[2] Gyula Vass[3] and Ferenc Varga[4]

Received: 09/02/2023 / Accepted: 05/07/2023 / Published online: 28/12/2023

Abstract Today, smart city principles are emerging as a highly relevant method in contemporary urban planning and development. In line with international trends, nations almost without exception have smart city strategies.

The assessment system supporting smart development strategies for EU municipalities defines complex indicators in six thematic sub-systems: smart mobility, smart environment, smart people, smart living conditions, smart governance, smart economy. One monitoring aspect of the smart living subsystem is safety. The smart cities of the future will be made up of a network of smart buildings, which will fundamentally determine fire safety based on prevention.

In this monitoring theme, the researchers will show how the future of fire safety - a cornerstone of safety- will evolve in smart buildings of smart cities. The researchers will describe the potential of building a smart fire safety network using data generated by building information modelling. They will show how BIM-based complex digital fire safety can be integrated into the fire safety network based on the new digital "one urban one plan" regulation in Hungary. The authors show that their method is suitable for the expansion of a smart cities database based on a digital urban plan.

Keywords: Smart city, Smart building, Fire safety, Fire protection, Urban planning

---

[1] Institute of Disaster Management Department of Fire Safety Engineering, University of Public Service, Hungary
* Corresponding author email: erces.gergo@uni-nke.hu
[2] Institute of Disaster Management Department of Fire Protection and Rescue Service, University of Public Service, Hungary
[3] Institute of Disaster Management Department of Fire Safety Technic, University of Public Service, Hungary
[4] Director of the Institute of Disaster Management, University of Public Service, Hungary

1. INTRODUCTION

Today, our society is facing new challenges that fundamentally require new guidelines for human development. The impacts already experienced from climate change and the projected changes call for a paradigm shift in the sustainable development of humanity. The need for the widest possible application of sustainable systems is now evident. The sustainability of civilised living conditions is an important issue in several fundamental aspects. These key aspects include the economy, energy efficiency, environmental protection and health and safety (Paton 2013).

What methods and tools can be used to achieve optimal sustainability? The problem is complex and therefore requires complex solutions. The complexity also stems from the intricate interplay of different aspects, which can be identified along network-like interrelationships. Solutions can be explored from multiple approaches, both professional and scientific. In this publication, the authors present the possible solutions for smart cities (Siddiquee *et al.* 2022).

In their research, they made the assumption that one of the pillars of sustainability is safety, of which fire safety is an integral part. It was assumed that by creating smart buildings and a network of smart cities, it would be possible to achieve a long-term sustainable level of fire safety that is higher than the expected level of safety defined by current legislation.

In their research, the authors summarised the technical parameters of today's smart buildings, and examined the technical and IT developments that can be expected in the near and longer term. The researchers integrated the above into the national fire safety system in order to compare it with the level of safety required by current regulations, and to assess the methodological development potential of smart cities in the field of urban planning on the basis of this framework.

For the analysis of smart buildings, the methodological framework for smart cities was used, which defines complex indicators for the development of smart cities in six thematic sub-frameworks: smart mobility, smart environment, smart people, smart living conditions, smart governance, smart economy. The authors have based their research on the monitoring aspects that can be identified within smart living environments, within which the safety monitoring aspect has been taken as the starting point (Kutty *et. al.* 2022).

2. RESEARCH OBJECTIVES AND METHODS

The researchers aim to develop a smart fire safety network that will lead to increased fire safety in smart buildings and that will provide long-term sustainable safety through the impact of smart building design. The aim is therefore to revisit the municipal plan by summarising the urban planning instruments in such a way that it serves the development of a smart city and thus provides a preventive protection in the field of safety (Okubo *et. al.* 2022).

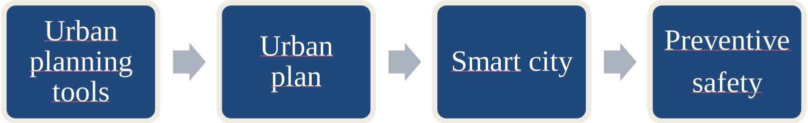

Figure 1. Objectives flow chart (made by the authors)

In order to achieve these objectives, the research used methods to digitise the urban planning instruments according to the "one urban one plan" methodology. We have created intelligent town planning tools that can form a complex database, which can lead to a preventive phase in fire protection that anticipates the possibilities of traditional fire prevention. Building information modelling was used to generate the data, while the data set was organised using network research methods.

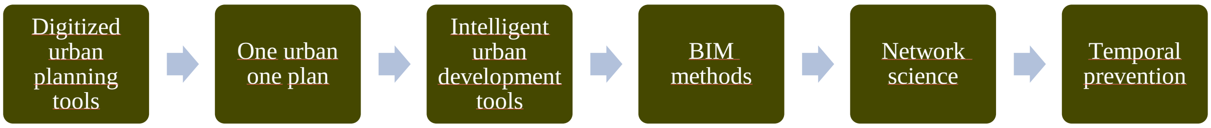

Figure 2. Methods flow chart (made by the authors)

3. SMART SYSTEMS

Today, there are countless smart devices available. Our phones, our TV, our fridge, our watch and so on are all smart, and we could go on and on about the many types and varieties of devices we have today. Not only are these devices available, but we have them and use them in countless households. What do we use them for, what function do they perform in our lives? The 4th industrial revolution, like the industrial revolutions that preceded it, enables us to use devices, systems and methods designed to make our lives more efficient, simpler, faster and, in short, more convenient. It is this convenience factor, and the commercial marketing built around these products, that makes most people want to own and use them. Sociological surveys and behavioural science therefore confirm the existence of a social need which is essentially human in nature and which can be defined by the concept of convenience (Kutty *et. al.* 2020)

In addition to the above, two other important factors can be identified for the need for smart systems, smart devices and smart buildings. One of these is the issue of energy efficiency, which is nowadays a key sustainability issue. The issue of sustainability therefore also generates a need for the use of smart systems. Energy efficiency, as a goal to be achieved, declares the need for smart buildings and smart cities (Ivars-Baidal, J. *et. al.* 2023).

According to statistics from Fire Safe Europe, people in Europe spend more than 90% of their time in enclosed spaces and buildings, so the way buildings are designed and how they behave is of paramount importance for sustainability. The UN's 2018 World Urbanisation

Report shows that 55% of the population now lives in urban areas. According to their analysis, this proportion is set to increase and, based on observed trends, 68% of the population is expected to live in or around cities by 2050. This is extremely significant in terms of the scale of the concentrated impacts, as cities cover only 3% of the planet's surface area, while consuming 80% of all energy used and accounting for 75% of all carbon dioxide emissions. Of the different types of buildings, residential and community buildings use 60% of electricity, 25% of fresh water and are responsible for 33% of the greenhouse effect. It can therefore be concluded that buildings are a significant factor in sustainability and have a major impact on our living conditions. Measuring these impacts, designing and maintaining their optimised functioning in the form of smart buildings is the most efficient way to address this need, and therefore today, meeting this need is an important task for development engineers and researchers (Firesafeeurope 2021).

The third key aspect for the use of smart systems is safety. Safety is a key factor in the application of smart systems, especially in terms of eliminating the human factor. Automated, intelligent systems are able to correct problems that may arise from human error without human intervention, by detecting and evaluating them and solving them through various controls. They are able to detect whether a window is left open, whether water is running, whether an electrical system is still live, whether there is movement in a room, *etc.* This structure also includes fire safety aspects, which, when connected to the control centre of the smart system, fulfil the above safety aspects via the fire alarm control panel. Nowadays, smoke, flame and heat are detected by means of appropriate detection units. The detected information is transmitted to the fire alarm control panel, which evaluates the incoming data and issues the necessary controls: sound an alarm, activate an evacuation light and sound system, close fire doors, dampers, locks, open heat and smoke protection devices, open heat and smoke exhaust vents, open fresh air supply vents, or activate mechanical systems for heat and smoke protection, but can also activate built-in extinguishing systems if properly designed. It can also implement additional controls and communicate with the smart safety system to activate camera images, transmit data to the fire brigade in the form of fire alarms, *etc.* It can therefore be concluded that the comfort and safety systems already available today, with a particular focus on property protection and automatic fire alarm systems, are available to play an important role in the construction of smart buildings. To sum up, it can be concluded that there is a practical need for smart buildings today, which offer solutions for users in three main ways:

-comfort
-energy efficiency
-safety

The network context for smart buildings is smart cities, which are a collection of smart buildings and other smart systems used in the development of urban areas (Gasco-Hernandez *et. al.* 2022).

4. SMART CITIES

"A smart city is a municipality or a group of municipalities that develops its natural and built environment, its digital infrastructure, the quality and economic efficiency of the services it provides, using modern and innovative information technologies, in a sustainable way and with the increased involvement of its inhabitants."

Sustainable urban development, carried out according to this methodology, applies horizontal aspects - high quality and efficiency, environmental and economic sustainability, increased involvement of the population - to the development of services and infrastructure. Information technologies integrated into the development and management toolbox help to achieve these objectives and monitor progress.

In principle, it is not possible to define a fully comprehensive, all-encompassing definition, but it can be said that the smart city development method is a methodology for urban development that provides one of the most innovative solutions for long-term sustainability.

The Smart City is essentially based on the EU Smart City Ranking and the Smart Cities Council index system, which identifies 6 sub-systems:

1. Smart governance
2. Smart transport
3. Smart environment
4. Smart economy
5. Smart living conditions
6. Smart people (Lechner 2018).

The Smart Living sub-scheme refers to measures to improve liveable cities, personal safety and health conditions (Lechner 2018).

The concept of the smart city first emerged in the mid-1990s, partly in the context of sustainable growth and partly in the context of ideas to reform urban governance systems. Today, smart city programmes can be broadly divided into two main groups and smaller specific projects:

1. eco-smart projects, which have been established since the 2000s, in the form of various greenfield investment projects launched as pilot projects. These were essentially eco-investments aimed at integrating the full range of smart solutions into the municipalities. These projects are at varying stages of completion, and it is not yet possible to draw any uniform and comprehensive conclusions from the pilot projects.

2. Projects established and intended to be implemented as a comprehensive strategy or programme element in existing cities are more effective than the above demonstration projects. In these projects, the smart ecosystem is integrated into existing cities and neighbourhoods, from intelligent transport and e-transport to e-government, *etc.* In these

projects, innovative data and information-based technologies play a key role (Rab-Szemerey 2018).

Smart city development model and monitoring system

The smart city development model is part of the integrated urban development strategy of the municipality in question in terms of strategy formulation, and sets the framework for monitoring the system. This will build long-term sustainability through the implementation of smart solutions.

These smart solutions also underpin the sustainability of safety. Building systems designed for long-term sustainability, modelled with intelligent building information, can rationalise and optimise the deployment of defences by analysing the risks involved. Intelligent built environments designed for strategically managed safety can be monitored, so that potential risk increases can be detected at an early stage and the necessary safety measures can be addressed at an early stage. In this methodology, safe long-term sustainability is achieved by applying a safety management system extended to a smart grid, a smart city (Bakonyi *et al.* 2016).

Another important aspect of the database-based collection of information obtained by the monitoring system is that by evaluating the results, more effective prevention can be achieved by taking into account the experienced, measured, accurate results. In future planning, the process will become more efficient as the information base grows, *i.e.* it will form a continuously increasing spiral that will allow the construction of large databases. The wealth of information, the continuously monitored ecosystem, endowed with artificial intelligence, will be able to map self-learning, self-improving processes. The system will evolve automatically, in response to external factors, as well as on its own.

To sum up, there is an established system, in the framework of which the system of smart cities can be analysed and evaluated by means of a specific measurement and monitoring methodology, a monitoring system, in order to meet the expected needs in terms of comfort, energy awareness and safety. The basis of the methodology is data, information, which can be generated and measured and monitored. This can be based on smart buildings as the basic units of the system (Érces *et al.* 2022).

5. SMART BUILDINGS AS THE BUILDING ELEMENTS OF SMART CITIES

What makes a smart building smart? The answer to this question is multifaceted and varies according to specific criteria. However, there is a generally accepted view that the following characteristics are fundamental to a smart building, as illustrated in figure 3:

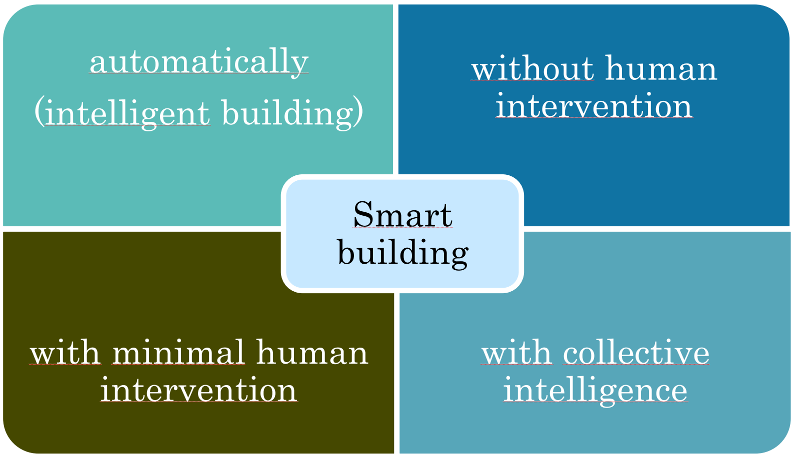

Figure 3. Attributions of smart buildings (made by the authors)

Summarizing the figure, it can be stated that the basic characteristic of a smart building is that it can operate automatically, intelligently, with minimal human intervention, in many cases without human intervention, and in many cases with collective intelligence. Activities with minimal or no human intervention require that automated systems be put in place, in whole or in part. This essentially requires the cooperation of three main factors:

- partially or fully automatic detection (*e.g*. temperature measurement, motion detection, smoke detection, *etc*.)
- partially or fully automatic assessment (*e.g*. using a control centre: heating control centre, safety control centre, fire alarm control centre, *etc*.)
- partially or fully automatic controls (*e.g*. activation of heating/cooling, alarm, fire alarm, *etc*.)

Collective intelligence is available as a combined system of these platforms that can communicate with each other, analyse and evaluate each other's information, *i.e*. it is the central evaluation, analysis and control unit of a smart building. Collective intelligence is the forerunner of artificial intelligence, which is already capable of implementing learning trends in certain application areas using artificial intelligence. The above process can be described in an exact way:

1. measured with sensors
2. analysed by software
3. algorithm for learning
4. with applications suggesting
5. intervenes in a technical sense (Sacks *et. al*. 2020).

Today's smart buildings, or smart functions typically integrated into buildings, use sensors in the building to detect the phenomenon they are measuring. The measured results and incoming data are collected, summarised and evaluated by software for analysing and evaluating the measurements. The software uses built-in or artificial intelligence learning algorithms to generate decisions, which are processed as output data by applications (built-in or mobile) that can be connected to the smart feature. Finally, it can also technically implement the controls as actual interventions. The above process shows the basic functional order of a smart building, by which our building becomes a smart building (Ruoxi *et al.* 2018).

The smart fire safety function of buildings can be integrated into this process to ensure the intelligent fire safety of a building. Smart fire safety must of course also meet the minimum safety level required by the relevant and applicable regulations. The expected level of safety at the regulatory level is not a universal constant level, but a function of the risks and a variable that responds to the level of risk. Its establishment must be incorporated into the smart functional order of the smart building, *i.e.* integrated into the smart processes. A general methodology for integrating smart fire safety in buildings is shown in figure 4. (Birkmann 2007).

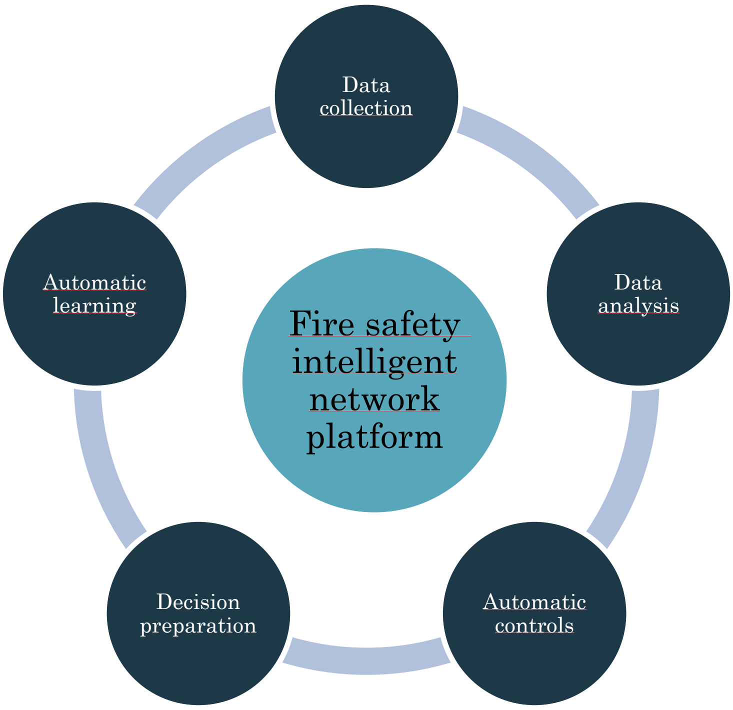

Figure 4. Attributions of fire safety intelligent network platform (made by the authors)

Identifying risks and determining the degree of vulnerability is the result of a complex process in which a network of system elements and actors, interconnected in space and time, provides the framework for investigations. The aim of fire safety analysis is to determine the fire safety situation of these complex interacting and closely interrelated technical fire safety parameters and fire safety factors. These parameter factors can perform a smart fire safety function using an intelligent network platform. The factors and parameters are used as data and information for the creation of smart building fire protection. The aim is therefore to manage this data, which can be done in two ways. The figure above summarises the solution based on data collection, where data is collected by sensing, observation and measurement. This is followed by further data management, which is of course based on the general methodology of smart buildings, *i.e.* data analysis and evaluation, followed by decision preparation and then by partially or fully automatic control interventions. It is of course also possible to integrate automatic learning in this methodology by using artificial intelligence. The key to this methodology lies in the science of network analysis (Kim *et. al.* 2021). The analysis and evaluation of a fire safety system that constitutes a complex fire safety network is based on the mathematical principles of network interdependencies, which make it possible to identify the key factors that essentially define the expected level of safety and fire safety of a given installation (Diekow 2021).

The above method is a post-event method, *i.e.* it can only analyse and evaluate phenomena that have occurred. This data is based on real, measured data, on which operational solutions can be provided to ensure the fastest possible response in time and at a rate calibrated to the measured event. One of the fundamental objectives of fire prevention is the timely identification of a fire in a facility. The aim is to detect and respond to an event as early as possible. To this end, the fire safety engineering aspects of the design process involve the optimal prediction of fire safety according to the expected level of safety. This is in many cases a unique process requiring specific custom solutions.

One aim of the authors' research is to apply the above method to smart buildings, which is possible by pre-integrating data into the above data-driven mechanisms. This requires the appropriate generation of data, which is addressed by building information modelling.

6. BUILDING INFORMATION MODELLING

The design of buildings and the processing of plans is now done using digital systems and computer software. These architectural and other complementary software are capable of creating a three-dimensional (3D) virtual space in such a way that the 3D elements intelligently carry information about the building: 'BIM, the process of building information modelling, is in fact an approach that treats the entire building process as a whole, from the design of the building to the end of construction (and even beyond, to the operation). BIM visualises and simulates projects with a powerful set of complementary solutions, makes documentation more efficient, manages data and facilitates complex collaboration between project participants. It provides a range of benefits throughout the project lifecycle for designers, construction professionals and, in use, owners and operators (Kreider-Messner 2013).” Individual building elements, structures, built building products carry in-formation that supports the design process and has the ability to perpetuate the information carried.

The basic concept of BIM: BIM is the application of CAD-based design methodologies and guidelines that allow the stakeholders involved in the construction and operation of buildings (builders, designers, contractors, operators) to collaborate and transfer information in a realistic virtual space and to visualise relevant data quickly and efficiently. The acronym "BIM" was originally derived from the initials of the term "Building Information Modelling", meaning the creation of virtual three-dimensional models with additional information. The "M" in the acronym is now often used to stand for "Management". The term Building Information Management refers to a process where, in addition to modelling and attributing model elements, the use of the system extends through all phases of the life cycle. It is based on the Building Information Model, also known as the BIM model (Koo-Shin 2018).

The process of producing a BIM model is in many respects the same as the process of pre-designing a 3D model, but is complemented by the loading of elements with reliable, codable information content, classification, and the combined use of specific modelling methods and rules.

Modelling and classification methods affect the quality and quantity of information that can be extracted from the model and its applicability. This sharing allows each actor to access the resulting model, to view and modify it with different privileges, to add to it the files they have created and to assign metadata to each element. Basically, there are two main ways of managing (creating, storing, transferring, modifying, *etc.*) information: open BIM and closed BIM. In the absence of standardisation, the various software vendors can achieve more efficient results in the short term by developing a closed BIM system within their own product families. Long-term development would require the use of open BIM, but the compatibility of open systems with each other is not yet nearly as efficient as with a closed system. This paradox creates a problem for development which has a fundamental impact on use even at the initial stages (Apanaviciene *et al.* 2020).

A classification system is a standardised or customized structure that allows building elements, structures and thus model elements to be grouped and classified into classes, thus facilitating subsequent queries and delimitations. The choice of the appropriate classification system has a significant impact on information management throughout the project. By using a classification system, the design, preparation, construction and operation processes can be managed in a single system. One of the most suitable versions of this solution from a fire safety point of view is IFC - Industrial Foundation Classes. IFC is an independent and open 3D object-based standard and file format that enables the transfer of information between construction CAD software from different developers by being able to describe spatial building elements used in construction with graphical and non-graphical data. The BIM model is used for sharing between project participants, comparing and integrating models from different disciplines. In addition to coordination during construction, it can also be used for engineering data storage and archiving. It is the basic format of the OpenBIM initiative. The development of IFC is carried out by building SMART In-ternational, in coordination with, but without the control of, the major software vendors. The IFC format is an ISO standard (ISO16739:2013), and has been adopted as a Hungarian standard (MSZ EN ISO 16739:2017). The so-called IFC objects include physical elements (walls, beams, windows, *etc.*) placed in the virtual model, rooms defined in CAD software and bounded by building structures, as well as additional elements needed for design (raster mesh, building outline, *etc.*) (Kreider-Messner 2013).

The BIM modelling process should ideally be familiar to all project stakeholders in relation to their own tasks. The combination of these capabilities brings together in one space, virtual space and time, all the actors involved in fire safety, in our case located anywhere in the world. In total, 7 BIM dimensions can be distinguished. (Nguyen-Oloufa 2001). If we look at the above from a fire safety design perspective, we obtain the following relationships:

Table 1. Summary of BIM dimensions in the point of view fire protection (made by the authors)

sssm.	dimension	Property	fire protection aspect	field of application
1.	*2D (CAD)*	*Vector graphics method projected onto 2D planes*	*traditional fire design method (widespread)*	*for simple constructions*
2.	3D (CAD)	Spatial method for geometric purposes only	advanced fire safety design method (spreading)	for complex structures
3.	3D BIM	information-centric advanced 3D geometric method	contemporary innovative fire design method (rarely used so far)	for any complex structures
4.	4D BIM	Beyond 3D BIM, coding for time schedulability	contemporary innovative fire design method (very rarely used so far)	for any complex structures
5.	5D BIM	Quantitative parameter coding beyond 4D BIM	contemporary innovative fire design method (very rarely used so far)	for any complex structures
6.	6D BIM	Beyond 5D BIM, encoding building physics, energy information	contemporary innovative fire design method (very rarely used so far)	for any complex structures
7.	**7D BIM**	Beyond 6D BIM, coding the information needed for sustainable use	contemporary novel fire design method (not yet used)	**for any complex structures for complex fire protection: design+FPTCM**

Based on the above, it can be concluded that 7D BIM is suitable for the long-term sustainable, user-oriented design and management of complex fire protection over the whole life cycle of a building. The model produced from building elements with 7D BIM content can form the virtual representation of the current Fire Protection Technical Conformity Manual (FPTCM), which can form the technical basis for the construction and use of smart buildings (Xie *et. al.* 2022).

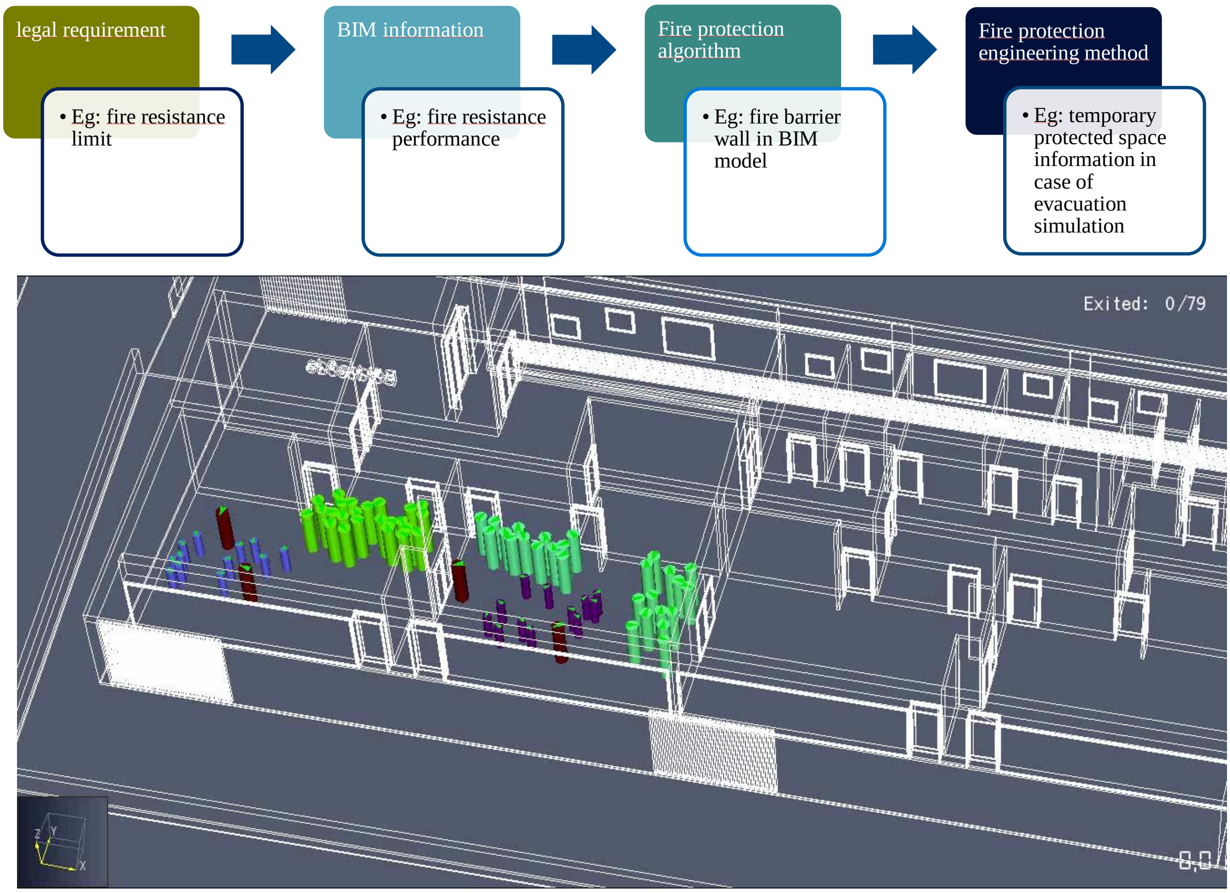

Figure 5. Flow chart and wireframe BIM modell analysis to a fire safety simulation (made by the authors)

The above method can be used to break down into exact system elements and to identify in a dedicated way all the technical fire safety parameters that can be tracked in a smart city system. (Rahman *et al.* 2021) However, for effective prevention, we need priority, primary technical data, which can be very heterogeneous for a single building, especially when considering an entire city. For these reasons, the researchers needed to introduce a new method (Cvetković *et. al.* 2022).

7. NETWORK SCIENCE METHODS IN FIRE PROTECTION

Network research has a specific subject and methodology. Network research is fundamentally an interdisciplinary science. This characteristic allows it to be used in the field of fire safety research. The important concepts and definitions of network research derive from graph theory, a specialised area of mathematics. However, network science differs from graph theory in that it is empirical and focuses on data and the usability of results. It not only involves describing and deriving properties in a mathematical sense, but also attempts to evaluate all tools on real data, based on the results obtained. If we want to understand a complex system, we need to know its components and the relationships between them, *i.e.* the connectivity map of our network. A network encompasses the building blocks of a system, called points or vertices in the discipline, while the connections between them are called edges (links). This common mathematical language provides a way of understanding and analysing systems, even those of very different nature, appearance or applicability. The number of nodes determines the size of a network, and the edges connecting them can be directed or undirected. The most important property of a point in a network is its degree number, which represents the number of connections between the point and other vertices in the network. For evacuation planning, the number of emergency exits, the distribution of the degree number, provides the basis for the fire safety of the system. If we want to describe a network in a complete way, we need to know the connections in the network. The weight of nodes in a network is not necessarily equal. From a fire safety point of view, an emergency exit door considered for mass containment does not carry the same weight as a door built into an evacuation route, so the quality of the connections must be weighted. In a weighted network, the elements of the adjacency matrix give the weight of the connections. The weight of edges, *i.e.* links, is not always well measured (Gosak *et. al.* 2022).

Metcalfe's law (circa 1980) states that the value of a network is proportional to the square of the number of points in the network. This theory is also perfectly applicable to the characterisation of a fire safety network, since the more technical fire safety parameters (nodes) are placed in the network, the more the value of the fire safety network increases, which can be determined by the square of the number of points according to the above law. In addition to the connectivity, the clustering property of a network, *i.e.* the clustering coefficient, shows how densely the neighbours of all points in the network are connected. Thus, the clustering coefficient measures the local connectivity density of a network. In turn, the clustering of the whole network can be measured by the average clustering coefficient. It gives, for example, the connectivity density of fire detectors, manual call points, which influences the quality of early detection and alarm (Barabási-Albert 1999).

One of the problems with fire protection systems is that they have to provide adequate protection at a very high safety level. The level of protection is typically set in proportion to the level of risk given or assumed. Identifying the various risks is an exact task: we can know how much and what quality of combustible material we have, how much smoke is likely to be generated in a room, how many people are in a building, how many exits are available for escape, *etc.* Of course, these parameters are more nuanced in real systems: we may not know where and how combustible material is located at any given moment, where smoke is flowing under given flow conditions, whether people are all following evacuation protocols, whether an emergency exit is closed for some reason, or whether escapees are taking advantage of emergency exits. To be more certain, we need to look at the risks in a complex way, at the rational options to solve the problems (Zanudo *et. al.* 2017).

Rationalising solutions is both an economic issue and a basis for long-term sustainability. At two extremes, it can be seen that there is a need for rational optimisation of solutions, *i.e.* designing the fire protection system to the optimum. If we aim at the minimum level of protection, we will be exposed to the extreme of the protection provided by a given solution. In the event of Soits failure, the system could fail completely, creating an unstable fire situation. If we move to the other extreme and try to apply all possible protection devices and solutions to a system, we will also create an unstable situation, in that the protection systems will weaken each other and thus work counter-productively (Teknős 2020).

Our task is to find the optimum. We need to map the orderliness of the fire protection system. We need to identify the problems, the sources of danger and their possible outcomes. Fault tree analysis and various risk assessments are good ways of doing this. However, in this way, we can only analyse the course of a series of events and not necessarily the behaviour of the whole system. In order to holistically examine the behaviour of the whole system, the task is to identify the spatial and temporal elements of the system, within which the degree of orderliness of the system, *i.e.* the entropy of the system, can be measured. The higher the degree of orderliness, *i.e.* the lower the entropy of the system, the more stable the fire protection situation (Schreurs *et. al.* 2019).

To model this and test the models, we apply network research methods to construct a fire network in which the weight of centres can be identified, degree number correlation, degree number distribution can be calculated, clustering coefficient can be determined, correlation of nodes can be measured, *etc.*, by which the expected processes and the optimal responses to them can be predicted in the system. Protection solutions can be dedicated to specific nodes, but also the interactions between the edges connecting the nodes can be identified by analysing the edges, so that the central protection elements that can have a predominantly negative impact on the whole network can be identified, and thus, by providing these nodes with a predominantly positive protection structure, a stable fire protection equilibrium can be optimally achieved in the long term (Piccolo *et. al.* 2022).

Fire networks are finite networks, all their points and the connections between them can be mapped. However, the degree of nodes does not indicate the quality of the connection between neighbours. We can map out the connections between fire detectors and manual call points, *etc.*, we can determine the degree number of the fire alarm control panel, *i.e.* its quantitative indicators, but to study their qualitative connectivity we need to know the clustering coefficient. Network science has proven that real networks are not random. Fire safety networks are not built, expand or contract as random networks, but behave in a planned way. In fire safety networks, too, the so-called small-world phenomenon applies, which means that short distances can be identified between two nodes in the network that are chosen at random, *i.e.* they interact, if not directly, then they interact. A fire door and a point smoke detector, although not directly connected at the system level, are connected through specific nodes and a process can be triggered by a signal from the detector, at the end of which, or as an intermediate step, the fire door closes, thus fulfilling its role in fire spread control. So we can create small worlds in the fire safety net in a conscious, planned way (Albert *et al.* 2000).

Since real networks have a finite property, the fire safety net is also a finite network. When nodes with a high number of degrees relative to the average degree distribution in a network are formed, midpoints are formed in that network. These midpoints have a crucial influence on the properties of the network. In a fire protection network, such nodes are crucial in determining the quality of the protection level, and therefore the design of these nodes in proportion to the risk is necessary when identifying and assessing risks. A well-weighted, well-designed node, *i.e.* a node with a high number of degrees and an appropriate clustering coefficient, can decisively determine the degree of fire safety, the establishment of a stable fire protection situation. In the 19th century, the economist Vilfredo Federico Damaso Pareto observed that in Italy 80% of the wealth is concentrated in just 20% of the population. His research showed that the 80/20 rule was fundamentally true and still seems relevant today. For example, 80% of web citations point to 15% of websites, or 80% of scientific citations go to 38% of the world's scientists, or during the 2009 global financial crisis, economist analysts showed that 1% of the US population owns 15% of all income (Cohen-Havlin 2010).

It can therefore be concluded that the interpretation of the rule may be relevant in the fire safety network. The extinguishing water intensity of a building consisting of many fire compartments is sufficient if it is sufficient for the fire compartment with the highest extinguishing water demand, since although it is a spatial network, the fire compartments form independent small worlds with their own special properties between which the fire spread can be prevented, so that only the property of the fire compartment, *i.e.* the centre, decides the extinguishing water intensity. It is equally true that although the transport system of a building forms a complex network from which prioritised and designated routes can be validated as escape routes. This is not because their spatial connectivity is adequate, but because their clustering coefficient is also adequate, so that they are included as a focal point in the transport system, such as a smoke-free staircase. We do not desmoke the whole building's circulation system, only the nodes with the right weight, *i.e.* the midpoints. The evacuation and escape system is not homogeneous in a building. It depends on the number of occupants, their wakefulness, their ability to escape, the number of floors they occupy, *etc.* Taking these parameters into account, the escape system network can be divided into small worlds which can be optimised in terms of fire safety, thus differentiating the level of fire safety of these small worlds. The risk of escape from the ground floor at the same level as the connecting ground floor, even if there are persons with restricted mobility, is not the same as that of escape from the thirtieth floor to the safe open air via twenty-nine floors. The establishment of appropriate small worlds also allows for a differentiation of the evacuation strategy according to the risks, with engineering solutions that are most optimal when evacuation is based on central nodes between small worlds, such as the formation of a temporary sheltered space system or the establishment of pressurised, smoke-free staircases or free staircases.

The nodes that determine the stability of a fire protection system, and therefore we need to ensure that the attack tolerance of these nodes is high, as the loss of these high nodes from the protection system will make the fire safety unstable. For a smart city system, we need to identify these nodes. In an optimized fire protection design, therefore, it is first of all necessary to ensure an adequate level of protection of the nodes in order to form a stable fire protection situation, for nodes with a low degree number a weaker protection, e.g. a single factor protection, may be sufficient for a holistic analysis of the complex stable equilibrium situation, or a scaling to an unstable equilibrium situation may be sufficient, since their role is peripheral. However, the protection of centres, in particular for fire protection networks with multiple centres, is crucial to avoid a possible domino effect that could lead to a fatal and total failure. Since the behaviour of nodes in a network depends on the behaviour of neighbouring nodes, they can lead to a chain reaction in case of negative effects, especially in terms of node densities that have a decisive impact on the system. To avoid this, a minimum level of protection proportional to the level of risk is required at each node of the fire safety net, but the safety of the system, *i.e.* the fire safety of the fire safety net, is determined by the adequately protected nodes (Barrat *et al.* 2012).

Removing a single node has little effect on a large network, but changing or removing multiple nodes, *etc.*, has a noticeable effect. In other words, a fire protection network can change dynamically during its life cycle, influenced by its use, its obsolescence, the hazardous nature of the activities, the quantity and quality of the combustible materials stored, *etc.* To maintain the required level of safety at an appropriate level, we need to identify these network nodes and monitor their status continuously. Life-cycle analyses must be carried out for the entire network so that the initial optimum can be maintained in the long term. (Fujita-Hatayama 2022)

Of course, the robustness of networks makes it difficult to solve this problem, but we can find help in the so-called percolation theory. This theory is a subfield of statistical physics and mathematics. An illustrative example of the theory is that if we put a pebble with probability p into the nodes of a square grid network and consider the adjacent pebbles to be connected, they will form clusters of two or more elements. Since the location of each pebble is random, there is the question of what is the expected size of the largest cluster and what is the average cluster size. The percolation theory points out that cluster size p is unlikely to vary uniformly, *i.e.* it is not possible to predict the variation unambiguously. This is typically true for a fire. For example, consider a forest fire and examine its spread. Suppose that the pebbles above are replaced by trees in the forest and the grid network is the forest. If a tree catches fire, the fire spreads to its neighbours, which indicates the connectivity of the nodes, *i.e.* trees, so that a chain reaction starts and the fire spreads from the neighbouring tree to the neighbouring tree. The question is, when does the fire stop, when can the fire stop spreading? The fire can stop spreading when no burning tree has a neighbour or no non-burning neighbour. This raises the fundamental question: if a tree catches fire in the forest, how much of the forest is burnt? The answer depends on the density of the trees. If the density of clumps is small, then the fire will go out relatively quickly, but if the density of trees is high, then we should expect a rapid and widespread fire spread, as the trees are part of a large cluster. Based on simulations carried out by researchers, there is a critical density value at which a long burn-out time should be expected. The above example illustrates the importance of the degree of clustering and its key role in fire spread control (Barabási 2016).

From a fire safety perspective, three network science concepts are of particular relevance to fire safety design:

1. Robustness, which shows whether a fire protection system will maintain its basic functions in the event of internal and external failures. By robustness we mean the ability of a fire protection system to perform its basic functions even if some of its nodes are missing. This is one of the most important principles to be achieved in terms of the robustness of a fire protection network. This principle is essentially applicable in the field of passive fire protection, which is the primary protection objective for a settlement.

2. Resilience, which shows whether a fire protection system can adapt to external and internal failures by changing its operation to maintain its functionality. This capability is therefore a dynamic property that plays an important and indispensable role in the field of active fire protection. It is the 'smart' factor in the system (Ohtsu-Hokugo 2019).

   Thus, for smart buildings and smart cities, a prioritised passive and a prioritised active set of properties are crucial for system safety.

3. In order to maintain the expected level of safety, a stable fire balance, a third very important concept must be understood and applied, especially for large and complex systems. This is redundancy, which means that protection components or safety functions are present in parallel, which can replace a missing component or function if necessary. For example, in the case of tall buildings, a duplicated fire water main (Barabási 2016).

8. ONE URBAN ONE PLAN

In Hungary, urban development and urban planning is one of the compulsory local government tasks to be carried out within the scope of local public affairs and locally provided public services. The purpose of urban development and urban planning is to improve the quality of life of the population and the competitiveness of the settlement by creating an urban structure and a high-quality environment for sustainable development, to enforce the public interest by ensuring the harmony of national, regional, municipal and legitimate private interests, to enhance and protect natural, landscape and architectural values, and to promote the sparing and environmentally friendly use of resources. One of the most modern ways of doing this is the smart city development method (Li *et. al.* 2022).

Spatial development defines the objectives of settlements, which are implemented through spatial development plans. Municipalities set out their intentions in a long-term urban development concept and a medium- to short-term integrated urban development strategy.

Town and country planning is responsible for establishing rules for the use of the land and plots of the municipality and for the local order of building:

- define the spatial and physical framework for the coordinated and orderly development of the municipality,
- promote the viability of the municipality by making effective use of its assets and potential, while minimising environmental damage,
- provide the infrastructure network necessary for the functioning of the municipality, and
- ensure the protection of the characteristic, valuable structure, built form, architectural, natural and landscape character of the settlement or parts of the settlement worthy of preservation (Kolossa, *et al.*, 2019).

Instead of the 6 separate plans and local government decisions currently used in Hungary (urban development concept, integrated urban development strategy, urban structure plan, local building regulations, urban image manual and urban image decree), the new concept proposes the preparation of a single urban plan, which can form a relevant basis for the development of smart cities.

The Urban Plan will be prepared by revising the current plan structure, keeping the most necessary elements and introducing new elements that fill gaps.

The current legal framework for town and country planning is a complex and complex set of rules that make it very difficult to develop settlements in today's rapidly changing economic environment. The current legislation does not even support the urban planning tasks of small settlements with stagnating and declining populations (Landsbergen *et. al.* 2022).

The requirements in the current legislation do not address the problems of climate change, the depletion of some raw materials and the challenges of sustainability. The current urban land-use plans in force do not address, or address only to a limited extent, issues related to the maintenance and enhancement of urban green spaces on the basis of current legal requirements. The New Approach aims to ensure that municipalities identify measures that provide a meaningful response and solution to both the development and maintenance of green spaces and climate risks, and that address the issue of safety as a key dimension of sustainability.

The new town and country planning legislation will provide significant help for both growing, economically strong settlements and stagnating, declining, economically backward ones.

As a result of the "one urban one plan" regulation:

- reduce the bureaucratic burden on municipalities in relation to town and country planning,
- priority investments of public interest will be easier and faster to implement,
- the preparation of the Urban Plan will be faster, easier and cheaper,

- the urban planning and the Urban Plan will be more transparent, easier to understand, and will present the directions of the urban 's development and its development intentions in a way that is comprehensible to the population,
- the new procedural rules will speed up the process of amending the Urban Plan and thus the implementation of construction projects,
- the set of rules for town and country planning will be differentiated, setting out the minimum content of the regulations that must be drawn up, while at the same time allowing larger or developing settlements to develop more complex local regulations,
- the preparation of the Urban Plans with a uniform content ensures coherence between national, regional, county and municipal plans,
- municipal planning will be fully digital,
- the new Urban Plans will create more transparent, predictable local regulation,
- the preparation of the Urban Plans will provide a planning basis for the EU programming period, so that available resources can be used more efficiently. (Kolossa, *et al.*, 2019)

The new one urban per plan method will become mandatory in Hungary from July 2027.

Into this new system, the researchers have integrated their fire safety network, created with BIM data, to improve sustainable safety and early preventive fire protection.

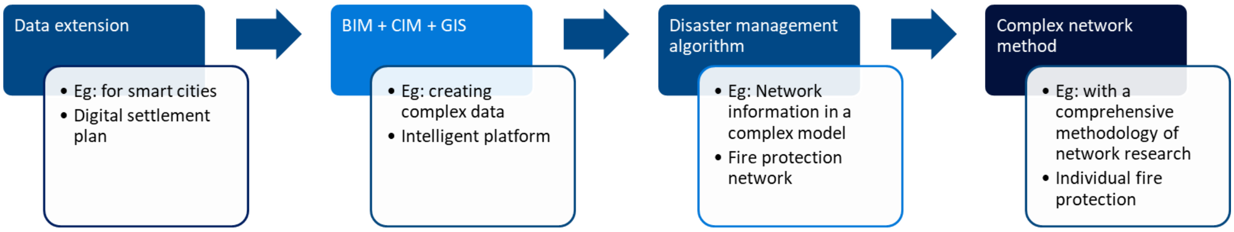

Figure 6. Flow chart of complex disaster management methodology (made by the authors)

By extending the data, digital spatial planning tools can be created to form a complex database of digital data. Information from this database can be monitored by disaster management algorithms, whose components measure the robustness and resilience of the fire safety net. The measured results will be used to draw up a complex fire safety network for the smart city, which can be used to integrate all the technical parameters for prevention during the planning phase. The key to the method is a fully digitised town planning system, which manages all the built-in regulators and technical parameters in a uniform format. This will create a complex and holistic database, forming a coherent network for all municipalities (Sacks *et. al.* 2004).

9. RESULTS

To paraphrase Albert Einstein: the disaster management and fire safety we have created is the result of our thinking. It cannot be changed or renewed by legislation alone, only if we change our thinking and our approach.

We see an opportunity for the development of disaster management in the development of complex fire protection based on innovative engineering methods, which can be created within the framework of the digital state using the available infocommunication tools. With the implementation of complex fire protection, a new quality of disaster management would be created, which would raise safety to a higher level.

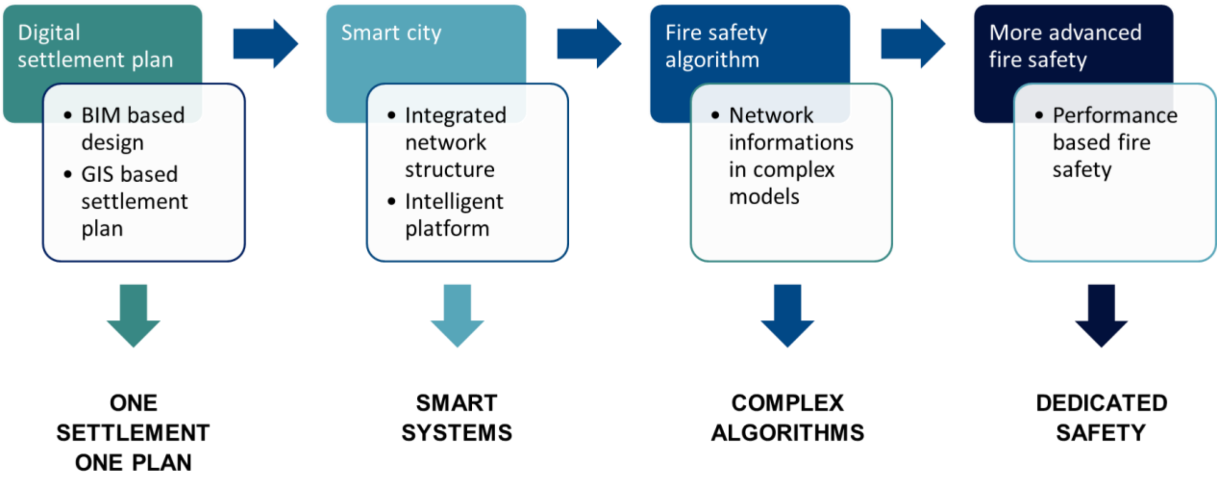

Figure 7. Flow chart of results (made by the authors)

The implementation and expansion of the system in the Smart Cities programme would form a comprehensive, unified disaster management network, serving safety throughout Hungary. By sharing the exact databases empirically obtained through monitoring in the structure of the digital state and augmented with artificial intelligence, a disaster management network could be created that could be extended to the entire territory of the European Union.

In the fire safety net, actors with the appropriate fire safety engineering competence are located in the same space and in real time. The result is a new, higher quality of fire safety in terms of design, construction, use and official procedures, which can be integrated into today's overall disaster management system.

10. CONCLUSION

In line with the objective, the main findings and conclusions are listed below:

- The innovative engineering method can be used to develop a long-term sustainable fire safety plan for the whole life cycle of buildings, and the information from the plan can be carried and dynamically modified throughout the life cycle of the building.
- The fire safety information encoded in BIM-based dynamic models, created using innovative engineering methods, can be used to create fire-smart buildings that provide a new level of protection and a more comprehensive quality of fire safety than is currently the case.
- By creating a stable fire equilibrium situation complexly extended over the whole life cycle of a fire-smart building, a virtual reality can be created that can be electronically applied to form a fire safety net.
- Smart buildings, created in the framework of the digital state, are a set of smart buildings with virtual information, 3D visualisable spaces with sensors, together with 3D mapping of open spaces, to form smart cities to which the fire safety net can be extended.

In conclusion, we have demonstrated that we can integrate BIM-based complex digital fire protection into a fire safety network based on the new digitalized one urban one plan scheme. Our derived method is suitable for data augmentation of smart cities based on digital urban plans. Using building information modelling, common information models and geospatial information systems, we can create complex data on a smart platform. Using this platform, we can create a complex fire safety network with disaster management algorithms. Finally, we can provide individual fire protection using a comprehensive network research methodology.

In our research, we explored the options available. The only system that is networked with the emergency services is the fire alarm system. This is the link between the smart city and fire protection. Our conclusion is that all next steps should be based on this, as all real-time data comes from this system. Through the fire alarm system we can control the integrated BIM information in real time.

The other conclusion of our research is that BIM-based complex digital fire protection systems should be integrated into this system to create a fire protection network. This fire safety network could be the key to the development of individual preventive fire protection and thus an improved fire safety.

FUNDING

Supported by the ÚNKP-22-4-II-NKE-7 New National Excellence Program of the Ministry for Culture and Innovation from the source of the National Research, Development and Innovation Fund.

Új Nemzeti Kiválósági Program

MINISTRY OF CULTURE AND INNOVATION

STATEMENT

The authors declare that the submission is original and has not been published or submitted for publication elsewhere.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Albert, R., Jeong, H., Barabási A.-L. (2000). Attack and error tolerance of complex networks, *Nature*, 406:378

Apanaviciene, R., Vanagas, A., Fokaides, P. (2020). Smart Building Integration into a Smart City (SBISC): Development of a New Evaluation Framework. *Energies, 13*(9), pp. 1-19. https://doi.org/10.3390/en13092190

Bakonyi, P., Cinkler, T., Csoknyai, T., Hanák, P., Kovács, K., Prikler, R., Rohács, D., Sallai, Gy. (2016). *Smart City solutions in six key areas*, Budapest, BME EIT, pp. 32., ISBN: 978-963-313-229-6

Barabási, A.-L. (2016) *Network Science*, Libri, pp.: 297-321. ISBN: 978-963-310-787-4

Barabási, A.-L., Albert, R. (1999). Emergence of scaling in random networks. *Science, 286*(5439), 509-512. https://doi.org/10.1126/science.286.5439.509

Barrat, A., Barthélemy, M., Vespignani, A. (2012). *Dynamical Processes on Complex Networks*, Cambridge University Press, UK. https://doi.org/10.1017/CBO9780511791383

Birkmann, J. (2007). Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. *Environmental Hazards, 7(*1), 20-31. https://doi.org/10.1016/j.envhaz.2007.04.002

Cohen, R., Havlin, S. (2010). *Complex Networks: Structure, Robustness and Function*, Cambridge University Press, UK. https://doi.org/10.1017/CBO9780511780356

Cvetković, V. M., Dragašević, A.,… Milošević, P. (2022). Fire safety behavior model for residential buildings: Implications for disaster risk reduction. *International Journal of Disaster Risk Reduction*, (76) pp. 1-24., ISSN: 2212-4209

Diekow, M.: Smart Buildings: Wie die Digitalisierung die Gebäudenutzung verändert, *FeuerTrutz*

Érces, G., Rácz. S., Vass, Gy. (2022). Fire Safety of Smart Cities in the Digital Future in: Bodnár, L. – Heizler, Gy.: *2nd Fire Engineering & Disaster Management Prerecorded International Scientific Conference (26. 04. 2022, Budapest) Book of Extended Abstracts*, Védelem Online, pp 60-64.

Fire Safe Europe. Fire safety: Know the facts http://firesafeeurope.eu/facts-figures (date of download: 15.11.2021.)

Fujita, S., Hatayama, M. (2022). Rapid and Accurate Detection of Building Damage Investigation Using Automatic Method to Calculate Roof Damage Rate. *IDRiM Journal, 12*(1), 89-114. https://doi.org/10.5595/001c.35885

Gasco-Hernandez, M., Nasi, G., Cucciniello, M., Hiedemann, A. M. (2022). The role of organizational capacity to foster digital transformation in local governments: The case of three European smart cities. *Urban Governance, 2*(2), 236-246. https://dx.doi.org/10.1016/j.ugj.2022.09.005

Gosak, M., Milojević, M.,… Perc, M. (2022). Networks behind the morphology and structural design of living systems. *Physics of Life Reviews,* (41), 1-21. https://doi.org/10.1016/j.plrev.2022.03.001

https://www.feuertrutz.de/smart-buildings-wie-die-digitalisierung-die-gebaeudenutzung-veraendert25082021?utm_source=Newsletter&utm_medium=FEU&utm_campaign=Ban daktuel +365_25.08.2021#3 (date of download: 20.12.2021.)

Ivars-Baidal, J. A., Celdrán-Bernabeu, M. A.,… Vera-Rebollo, J. F. (2023). Smart city and smart destination planning: Examining instruments and perceived impacts in Spain, *Cities* (137), pp. 1-15. https://doi.org/10.1016/j.cities.2023.104266

Kim, J., Park, J.,… Kim, M. (2021). RnR-SMART: Resilient smart city evacuation plan based on road network reconfiguration in outbreak response. *Sustainable Cities and Society*, 75, 1-13. https://doi.org/10.1016/j.scs.2021.103386

Kolossa, J., Gombos, M., Kállai, K. (2019). New Directions in Urban Planning in Hungary, One urban – One plan, https://doi.org/10.31852/EMF.31.2019.092.099 (date of download: 09.05.2022.)

Koo, B., Shin, B. (2018). Applying novelty detection to identify model element to IFC class misclassifications on architectural and infrastructure Building Information Models. *Journal of Computational Design and Engineering 5*(4), 391-400. https://doi.org/10.1016/j.jcde.2018.03.002

Kreider, R. G., Messner, J. I. (2013). The Uses of BIM: Classifying and selecting BIM Uses, The Pennsylvania State University, University Park, PA., USA., http://www.bim.psu.edu (date of download: 10.02.2020.)

Kutty, A. A., Abdella, G. M., Kucukvar, M., Onat, N. C., Bulu, M. (2020). A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals. *Sustainable Development, 28*(5), 1347-1365. I https://doi.org/10.1002/sd.2088

Kutty, A. A., Kucukvar, M.,… Onat, N. C. (2022). Sustainability Performance of European Smart Cities: A Novel DEA Approach with Double Frontiers. *Sustainable Cities and Society,* (81), 1-22. https://doi.org/10.1016/j.scs.2022.103777

Landsbergen, D., Girth, A., Westover-Muñoz A. (2022). Governance rules for managing smart city information. *Urban Governance, 2*(1). https://doi.org/10.1016/j.ugj.2022.05.003

Lechner Tudásközpont. Smart City. http://okosvaros.lechnerkozpont.hu/hu. (date of download: 11.10.2019.)

Li, L., Taeihagh, A., Tan, S. Y. (2022). What factors drive policy transfer in smart city development? Insights from a Delphi study. *Sustainable Cities and Society,* (84), 1-12. https://doi.org/10.1016/j.scs.2022.104008

Nguyen, T.,Oloufa, A. A. (2001). Computer-generated building data: Topological information. *Journal of Computing in Civil Engineering,* 15(4), 268-274. https://doi.org/10.1061/(ASCE)0887-3801(2001)15:4(268)

Ohtsu, N., Hokugo, A. (2019). Feedback Process of a Tsunami Evacuation Plan Using Quantitative Data of Drills for Supporting Vulnerable People in a Community. *IDRiM Journal*, *9*(2), 1-20. https://doi.org/10.5595/idrim.2019.0352

Okubo, H. Shimoda, Y.,…. Deto, K. (2022). Smart communities in Japan: Requirements and simulation for determining index values. *Journal of Urban Management 11*(4), 500-518. https://doi.org/10.1016/j.jum.2022.09.003

Paton, D. (2013). Disaster Resilient Communities: Developing and testing an all-hazards theory. *IDRiM Journal*, *3*(1), 1-17. https://doi.org/10.5595/idrim.2013.0050

Piccolo, S. A., Lehmann, S., Maier, A. M. (2022). Different networks for different purposes: A network science perspective on collaboration and communication in an engineering design project. *Computers in Industry*, *142*, 1-18. https://doi.org/10.1016/j.compind.2022.103745

Rab, J., Szemerey, S. (2018). *Smart City Development Modell Methodological Basis*, Lechner Knowledge Center

Rahman, M. A., Hokugo, A., Ohtsu, N., Chakma, S. (2021). Evacuation Preparation Scenarios of Households during Early and Energency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh. *IDRiM Journal*, 11(2), 108-137. https://doi.org/10.5595/001c.29128

Ruoxi, J., Baihong, J., Ming, J., Costas, J. (2018). Design Automation for Smart Building Systems. *IEEE*, *106* (9), 1680-1699. https://doi.org/10.1109/JPROC.2018.2856932

S. M. S. Siddiquee, S. M. S. , Khan, Md. M. H….., Ahmed, H. (2022). Blockchain applications in smart sustainable city context—A systematic mapping study. *Energy Reports,* 8, Supplement 15, 162-169. https://doi.org/10.1016/j.egyr.2022.10.102

Sacks, R. Eastman, C. M., Lee, G. (2004). Parametric 3D modeling in building construction with examples from precast concrete. *Automation in Construction 13*(3), 291-312. http://dx.doi.org/10.1016/S0926-5805(03)00043-8

Sacks, R., Girolami, M. Brilakis, I. (2020). Building Information Modelling, Artificial Intelligence and Construction Tech. *Developments in the Built Environment,* (4), 1-9. https://doi.org/10.1016/j.dibe.2020.100011

Schreurs, W., Kerstholt, J. H., Vries, P. W., Giebels, E. (2019). Community Resilience and Crime Prevention: Applying the Community Engagement Theory to the Risk of Crime. *IDRiM Journal*, (*9*)2, 70-90. https://doi.org/10.5595/idrim.2019.0359

Teknős, László (2020). Sustainability aspects of disaster management, Georgikon for Agriculture: A Multidisciplinary. *Journal in Agriculturural Sciences 24*(4), 103-116

Xie, M., Qiu, Y.,… Zhang, G. (2022). Policies, applications, barriers and future trends of building information modeling technology for building sustainability and informatization in China. *Energy Reports*, (8), 7107-7126. https://doi.org/10.1016/j.egyr.2022.05.008

Yamori, K. (2011). The Roles and Tasks of Implementation Science on Disaster Prevention and Reduction Knowledge and Technology: From Efficient Application to Collaborative Generation. *IDRiM Journal*, 1(1), 48-58. https://doi.org/10.5595/idrim.2011.0009

Zañudo, J. G. T., Yang, G., Albert, R. (2017). Structure-based control of complex networks with nonlinear dynamics. *PNSA*, *114*(28), 7234-7239. https://doi.org/10.1073/pnas.1617387114