Holonic System for Real-Time Emergency Management in Buildings

B. Naticchia[a], L. Messi[a], M. Pirani[b], A. Bonci[b], A. Carbonari[a], and L.C. Tolve[a]

[a] Polytechnic University of Marche, DICEA, via Brecce Bianche n. 12, Ancona, Italy
[b] Polytechnic University of Marche, DII, via Brecce Bianche n. 12, Ancona, Italy
E-mail: b.naticchia@univpm.it, l.messi@staff.univpm.it, massimiliano.pirani@gmail.com, a.bonci@univpm.it, alessandro.carbonari@staff.univpm.it, l.c.tolve@pm.univpm.it.

Abstract –

Emergency management can benefit from advanced information and communication technology (ICT), since it can support officers in charge of emergency management to deal with urgent decision within a really short deadline. Further enhancement can derive from the application of holonic systems, which typically deal with the unexpected. In fact, unexpected events may prevent the application of emergency plans, e. g. evacuation of people outside of a building in fire through a network of pre-determined paths.

The holonic emergency management system, proposed in this paper, guarantees the shift to a contingent approach, leveraging the flexibility and adaptability to changing scenarios deriving from the holonic theory. Last but not least, the BIM integration provides all the building's topological information. Such a technology can exploit general data to automatically detect unconventional ways out and arrange rescue operations in real-time. The developed system has been applied to the fire safety management of a large building in a university campus. The BIM model of the case study has been imported in a game environment where an unconventional pathfinding has been experienced.

Keywords –

Holonic System; Emergency Management; Fire Safety; BIM.

1 Introduction

1.1 Building Management System

Building automation systems (BAS), also known as building management systems (BMS), denote a wide range of computerized building control systems, from special-purpose controllers, to standalone remote stations, to larger system including central computer stations. A BAS comprises several subsystems which are connected in various ways to form a complete system. The system has to be designed and engineered around the building itself to serve the services systems for which it is intended. Consequently, although the component parts used may be identical, no two systems are the same, unless they are applied to identical buildings with identical services and identical uses [1]. BMS, with their typical hierarchical structure, are usually able to reach their goals in an efficient way and with no faults, whereas they fail to stick to pre-determined targets in the presence of disturbances. In fact, traditional systems cannot pursue the assigned task if any unforeseen events occur. Their rigid structure makes it very difficult to tackle unexpected scenarios. As low-level modules have to consult higher hierarchy levels in case of a disturbance, their reactivity becomes weak. Furthermore, global decision-making is often based on obsolete information [2]. Building services include HVAC systems, electrical systems, lighting systems, fire systems, security systems and lift systems. In industrial buildings they may also include the compressed air, steam and hot water systems used for the manufacturing process [1].

In this paper, fire and security systems for the emergency management will be studied in depth in order to overcome the limits of the traditional BMS. Emergency management, since directly affects safety of people, represents a relevant issue in each phase of building lifecycle, from a foresighted design of buildings and infrastructures to the elaboration of emergency plans according to specific regulations. Emergency scenarios are even more relevant as case studies, if the high frequency of unexpected events affecting them is considered. The traditional approach to the emergency management is based on a deterministic forecast of main scenarios. The emergency plan resulting from them has a key role, although it does not consider the totality of possible scenarios. As a consequence, it is regardless of contextual, changing and unexpected events that may happen and seriously affect the effectiveness of emergency measures.The limits of such a knowledge-based approach are confirmed by several examples of complications in the emergency operations. To name one, during the emergency response to the September 11, 2001 attack on the World Trade Centre, commanders on the scene were unable to communicate to '911' Public Service Access Points (PSAP) that people should evacuate the building [3]. As a result, PSAP operators complied with New York City's standard operating procedure for hi-rise fires and advised callers to stay in impacted buildings. The '911' system was inadequate for handling a major disaster and could not adapt to the emergency. The final death toll 2749 may have been substantially reduced if the PSAP's were adaptive in coping with the overload. Moreover, commanders trying to evacuate fire fighters from the north tower during the World Trade Centre disaster were seriously hampered by ineffective radio communications; the final death toll 343 of New York fire fighters may also have been substantially reduced if the system controlling the radio communications was also adaptive [3]. To name another example, the Grenfell Tower fire produced a high number of victims not only for technical reasons, due to the employment of a not proper cladding system and to a lack of separated fire boxes into the building, but also to a mistake in the emergency evaluation [4]. The "stay put" strategy, led by a tardive declaration of the situation as a major incident with the consequent delay of one hour in the evacuation process, has revealed as a fatal mistake in the rescue operations [4]. Furthermore, a traditional emergency plan does not facilitate the operational use. In fact, it remains as a plain-text document which is difficult to consult during an excited situation due to an oncoming danger. In other words, a way out plan hung on the wall cannot help incisively to find a viable exit route. The fire in the Rhode Island station club represents an example of how a not profound knowledge of the building in which people were located affected the evacuation process: a study has demonstrated that people did not use alternative ways out since they ignored their presence [5]. While the main exit doors were obstructed by the smoke presence, there were no indication to use alternative paths to escape from the building; therefore, the evacuation process was affected by a fatal delay [5].

Starting from this shortcomings, the current research proposes a contingent approach which exploits a BIM-based holonic technology to overcome the limits of the traditional BMS. The developed holonic management system integrates a building digital model, which provides all the necessary data for the real-time detection of ways out. This paper is organized as follows. Section 2 provides a description of the system architecture. Section 3 describes the Virtual Reality Platform. Section 4 provides a description of the Bayesian Selector. Section 5 describes the generation of Multi-Target Partial Plans for the considered case study. Section 6 provides a description of the Combiner and shows the simulations results. Section 7 is devoted to conclusion.

1.2 Holonic Theory

The holonic concept, which is the basis of holonic management systems, is the key enabler to tackle unexpected events and overcome the limits of the traditional BMS. The holonic theory was introduced in 1967 by Koestler [6] to explain the evolution of biological and social systems. Likewise, in the real world, where almost everything is at the same time a part and a whole, each holon can be part of another holon [2]. In fact, the word holon is the combination of "holos", which in Greek means "whole", and the suffix "on", which suggests a part [7], [8], [9]. In the manufacturing field, holons are autonomous and cooperative building blocks, since they can both control the executions of their own strategies and develop mutually acceptable plans [2]. Furthermore, holons consist of an information-processing part and often a physical-processing part [2], [7], [8]. The former is responsible for high-level decision making, collaborating and negotiating with humans and other holons, while the latter is a representative of its linked physical component and responsible for transferring decisions and instructions to it [7]. According to Koestler, a holonic system or holarchy is then a hierarchy of self-regulating holons that function (i) as autonomous wholes in supra-ordination to their parts, (ii) as dependent parts in subordination to control at higher levels, and (iii) in coordination with their local environment [2], [6], [9]. Therefore, holonic architecture combines high and predictable performance, which distinguishes hierarchical systems, with the robustness against disturbances and the agility typical of heterarchical systems [8]. In this way, systems' resilience is guaranteed. Holonic management systems, which have been successfully applied in the manufacturing field, can constitute a novel technology to tackle unforeseen scenario variations. Indeed, the autonomy and cooperation of their elementary units, the holons, makes it possible to avoid the rigid structure of hierarchical systems and therefore respond quickly to disturbances [2].

2 System Architecture

The architecture of the developed holonic system, depicted in Figure 1, supports fire emergency management and rescue operation, detecting the most effective way out. Its aim is not to substitute the actual approach foreseen by regulations, rather to enhance the standard emergency plan, detecting unconventional path to exit the building, if an unexpected event occurred. The architectural principles are shortlisted as follows:

- *Real-time effectiveness*: it must regard both the information flow and the decision making process.

Since the system is continuously evolving, especially in complex scenarios like emergencies, it is not feasible to represent all the changing status it assumes, in order to provide the proper solution to the occurring situations. Moreover, the response of the system must be sufficiently reactive in order to result effective to face the situations that are in place.

- *Proactive and unconventional problem solving*: on the basis of the information gathered in a real-time manner, the system, in order to be sufficiently resilient, must be capable to extract the information useful to reach its objectives also by general data, as well as to provide escape solutions with the employment of unconventional means.
- *Resilience*: the system must be reactive and adaptive to the new possible configurations that may occur, without compromising its primary function of managing the emergency scenario. Failure, interruptions, damages to the standard communication backbone systems, as well as injuries or obstructions to the usual evacuation means, must not impede the main objective of keeping people safe during emergencies.
- *Emergent cooperation*: the system architecture embodies the capability of the holons to cooperate in temporary associations, namely the holarchies, introducing the "emergent cooperation". This concept can be described using a metaphor: the behaviour of these agents is similar to the one belonging to the birds of a flock; no one is able to manage flock's shape and dimension, but everyone takes care of maintaining flock's trajectory, flock's speed and minimum distance from its fellows. Although no one of the birds has a complete view of the scene, the behaviour described above is the result of an "emergent collaboration". This kind of cooperation is not so onerous for birds because it is supposed to be integrated within their DNA and, therefore, instinctive. The same functioning characterizes the agents inside the developed architecture.

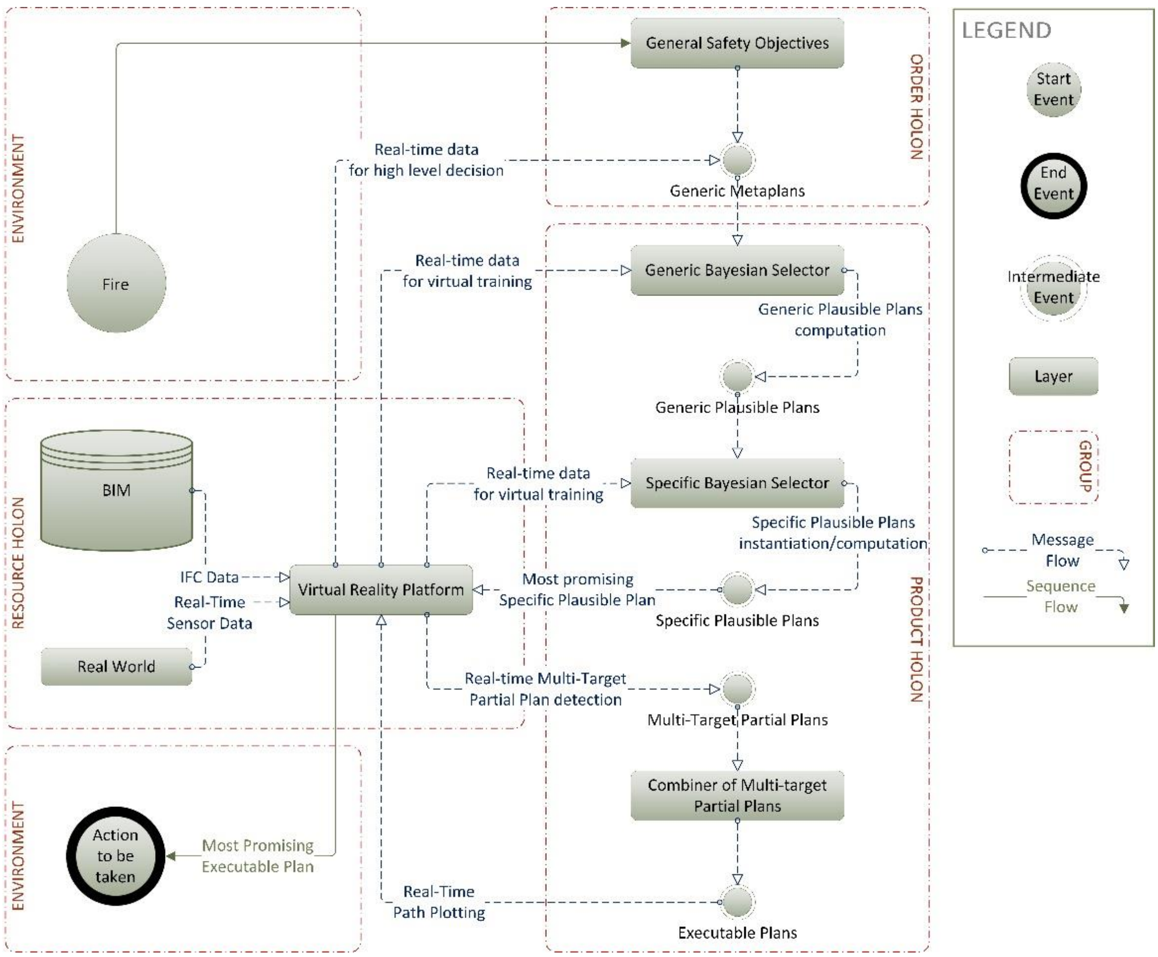


Figure 1. System architecture of the developed holonic management system

The system architecture in Figure 1 is composed by different layers interacting each other according to a publish/subscribe scheme, whose central concept is the notion of *topic*: each node/layer of the architecture subscribes and some other publishes information on the *topic*. In other words, the *topic* is simply the database content itself without intermediate language adapters: the unique language is the database language and its queries. Hence, the architecture layers behave like a human being that only subscribes to interesting events/information and publishes relevant events/information, which are specifically useful for the occurring situation, complying to the actual needs [10].

The different layers can be clustered by function according to the PROSA reference architecture [2], a conceptual architecture for manufacturing control, that has shown great potentialities to be applied also in different context. The acronym PROSA stands for *product-resource-order-staff architecture* and refers to the different types of holons. Three basic types of holons can be distinguished: product holons, resource holons, and order holons. Staff holons are optional and can be added to provide the other holons with expert knowledge [2]. In PROSA, the holons' physical part belongs to the world of interest, that is the part of reality which falls within a certain scope relevant for the application [8]. In Figure 1, the PROSA analogy is highlighted identifying resource, product and order holons. Finally, the environment is the real world scenario where the holons operate, namely the fire occurring and the countermeasures to be taken at the end of the elaboration process.

The highest architecture layers, namely the General Safety Objectives and the Generic Metaplans (see Figure 1), correspond to the order holon, which in the manufacturing system represents a task that needs to be executed, for example the delivery of a package [2]. The General Safety Objectives represents the always valid target: "Save all the people inside the building". As a consequence, the Generic Metaplans are triggered and fed with real-time data from the Virtual Reality Platform. The output of this elaboration are the general processes to be executed, which may be represented by the generic instruction "Stay in/go out" and are published to the following layer. Thanks to the generality of the high level setting, the resilience architectural principle is guaranteed and the resulting system is applicable for every building, without the need to configure it manually every time. This is a key feature that distinguishes the developed architecture from classic BMS.

3 Virtual Reality Platform

The Virtual Reality Platform (VRP) is the heart of the resource holon, which in the logistic context corresponds to resources like all transport means and material handling equipment [2]. In the developed system, the VRP is implemented using the Unity 3D game engine. It has been selected as the most suitable tool because of the following characteristics:

- high interoperability with other software, including the capability to integrate several functional mockups afferent to different engineering disciplines;
- presence of a physics engine that provides physical behaviour to the components of the scene, basically the correct acceleration and the affections by collisions, gravity and other forces, making the simulation of a great likelihood with the real world;
- possibility to introduce artificial intelligence by scripts, based on C# or Java programming languages, or by means of visual programming.

In other words, Unity 3D offers an extremely realistic environment to simulate a fire emergency scenario of the case study and building occupants' behaviour using artificial intelligence. The VRP constitutes a dynamic hub able to collect IFC data from BIM and real-time data from pervasive sensors distributed in the real world. The interconnection with the BIM software Autodesk Revit has been established through an IFC Loader, based on the IFCEngine DLL Library [11]. This component makes it possible to import contextual, geometrical, material properties from the BIM, once exported in IFC format. The interconnection with sensors, which has not been tested in this research step, is one of future developments. The technological solution to this issue is ASP.NET Core SignalR, an open-source library that simplifies adding real-time web functionality to apps. Real-time web functionality enables server-side code to push content to clients instantly [12]. The building digital model, coherently updated during the whole lifecycle, provides in real-time accurate topological information, that goes further beyond the static and poor information usually contained in emergency plans. In this environment, the Unity 3D asset A* Pathfinding Project Pro (A*PPP) [13], applying the A* algorithm, detects the most effective way out. If the usual escape route is obstructed by smoke, fire, collapsed building elements or other kinds of accidents, the A* algorithm can detect unconventional ways out through internal doors. Moreover, BIM is proposed not only as a comprehensive provider of the main building properties, but it is subjected to a proper semantic enhancement: some building elements can be exploited in an unusual way in respect of their main purpose and become evacuation means in an unconventional manner. This contribution appears even more relevant, if we consider the possibility to have random visitors inside building, affected by a poor awareness of the spatial distribution. As depicted in

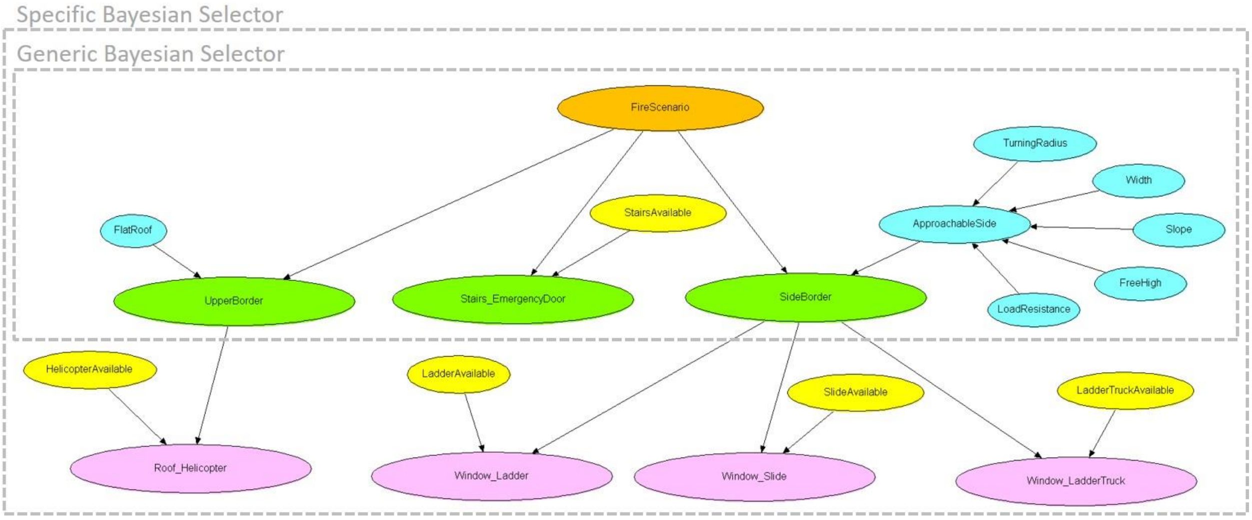


Figure 2. Bayesian Selector

Figure 1, the VRP acts as a collector of heterogeneous data and represents the proper environment where the required knowledge can be produced and published. In this way, real-time data are available for each subscribing layer of the architecture.

4 Bayesian Selector

The Bayesian Selector (BS) is conceived as the translation into a Bayesian network of an expert's knowledge. Bayesian networks, which constitute a powerful mean to represent phenomena affected by a high level of uncertainty, are a probabilistic graphical model that uses Bayesian inference for probability computations. They aim to model conditional dependence, and therefore causation, by representing conditional dependence by edges in a directed graph. Through these relationships, one can efficiently conduct inference on the random variables in the graph through the use of factors [14].

In the fire emergency management, the BS, fed by real-time data from the VRP, detects which strategy or plan is probabilistically the most effective to exit safely the building in fire. As shown in Figure 1Figure 2Figure 1, it is composed by a generic part and a specific one, respectively linked to Plausible Plans and Multi-Target Partial Plans. The Generic Bayesian Selector suggests the most effective preliminary escape strategy (called also Generic Plausible Plan) amongst those ones valid for any building. The Specific Bayesian Selector detects the most promising escape plan (called also Specific Plausible Plan), instantiated for the analysed building. All these layers, according to the PROSA analogy, constitute the product holon, which contains the knowledge on how instances of a specific task type (represented by order holons) can be executed by the resources [2].

4.1.1 Generic Bayesian Selector

The Generic Bayesian Selector subscribes data deriving from Generic Metaplan and is trained by real-time data published by the VRP; as output, the most effective Generic Plausible Plan is computed (see Figure 1). In details, when the "Fire Scenario" (see orange node in Figure 2) is activated by the alarm, the Bayesian network computes which Generic Plausible Plan (see green nodes in Figure 2) should be analysed in depth in order to find a viable exit route. The "generic" attribute means that the Generic BS is applicable for every building. As a matter of fact the green nodes in Figure 2 represent the possibilities to exit any building:

- "Stairs and Emergency Door" represents all the exit routes which exploit stairs and emergency doors. They comprise not only the standard exit route suggested by the emergency plan, but also alternative and unconventional ways out through internal doors connecting adjacent rooms.
- "Upper Border" and "Side Border" represent the building's frontiers where rescue teams could pick up and save endangered people. They comprise only the unconventional ways out, detected when an unexpected event voids the standard emergency plan.

Finally, blue nodes represent building's features (for example "Flat Roof", in Figure 2, stands for "Is the building's roof flat?") whereas yellow ones represent resource availability (for example "Stairs Available", in Figure 2, stands for "Are the building's stairs available/viable?").

4.1.2 Specific Bayesian Selector

The Specific Bayesian Selector integrates the generic one adding the Specific Plausible Plans (see purple nodes in Figure 2). It subscribes data deriving from Generic BS and is trained by real-time data published by the VRP. On the base of these data, the technology described in [15] and [16] is able to instantiate in real-time the Specific Plausible Plans for the emergency management of the considered building. As output, the most promising Specific Plausible Plan is detected (see Figure 1). In Figure 2, four Specific Bayesian Plans, instantiated for the building case study, are reported as examples:

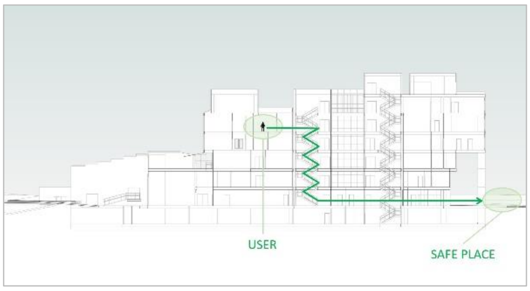
- "Roof and Helicopter" which stands for "Lead people to the roof and pick up them by a helicopter";
- "Window and Ladder" which stands for "Lead all people to the window and pick up them by a normal ladder";
- "Window and Slide" which stands for "Lead all people to the window and use a slide";
- "Window and Ladder Truck" which stands for "Lead all people to the window and pick up them by a ladder truck".

5 Multi-Target Partial Plan

5.1 Description of the case study

In order to implement and test the developed architecture, the mixed-use building "Eustachio", located in Ancona (Italy), has been chosen. The building belongs to a major complex of edifices occupied by the Faculty of Medicine of Polytechnic University of Marche. This eight storeys-building presents a quite regular shape with two major blocks on the north and south side, containing spaces devoted to heterogeneous scopes: classrooms, scientific laboratories, administrative offices for students, a library, books storage rooms, services. The two main blocks are connected by two double stairwells, which present a separate reinforced concrete envelope that makes these parts separated from the block for seismic reasons. The choice has fallen on this edifice for its characteristic of public building with several uses that may involve variable flow of different people inside it: estimated between 100 and 2320 individuals and characterized by several age ranges and, more specifically, owning a different level of knowledge of the building. Finally, the presence of inflammable substances in several laboratories leads to simulate the fire scenario in this building, since this is one of the most common and disruptive emergency situation, often affected by unexpected events and mistakes in the management of the evacuation process.

a.



b.

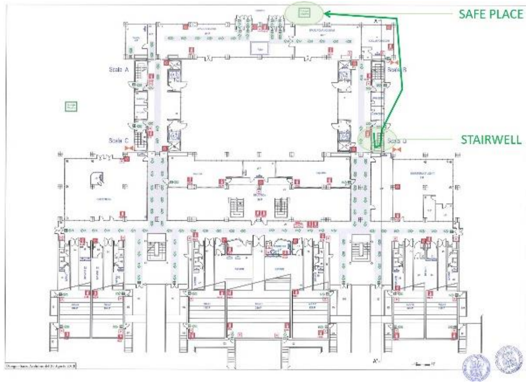


Figure 3. Example of exit route according to the Eustachio's emergency plan: section view (a.) and ground floor plan view (b.)

5.2 Strengths of the system

The traditional approach to the emergency management is based on a deterministic forecast of a finite number of main scenarios. Unfortunately, unexpected events could prevent the effectiveness of the pre-determined paths defined by the standard emergency plan. According to the Eustachio's one, as shown in Figure 3.a. and Figure 3.b.Figure 4, a user, in whatever floor he is, should reach the closest stairwell, go downstairs until the ground floor and, finally, exit the building. It may not be the best solution to run away from a building in fire, especially if an unforeseen event occurs and the usual escape route is unviable. In other words, the obstruction of a path by operators in charge of operation and maintenance or the collapse of non-structural components, like ceilings, may have tragic consequences during a fire. The developed holonic system detects alternatives and unconventional ways out in real-time, overcoming the limits of an a-priori plan. Hence, officers in charge of emergency management can benefit of the proposed system's computing capability and nimbly coordinate rescue operation.

5.3 Generation of Multi-Target Partial Plans

The developed holonic system, as mentioned before, can tackle unexpected events, providing in real-time unconventional paths outwards. More in details, the pathfinding, carried out in the VRP by means of the A* algorithm (see Section 3), detects the Multi-Target Partial Plans (see Figure 4). Given the most promising Specific Plausible Plan, the A*PPP detects automatically all the possible routes towards intermediate points. For example, assuming that the Bayesian Selector has classified “Window and Ladder Truck” as the most effective Specific Plausible Plan, the VRP by means of A*PPP provides the following Multi-Target Partial Plans:

- all the shortest paths (see blue lines in Figure 4) from the endangered user towards all the building’s windows, assumed as intermediate points and identified by their GUID (Globally Unique Identifier);
- all the shortest paths (see red lines in Figure 4) from the rescue team, represented for example by the ladder truck, towards the building’s windows.

6 The Role of the Combiner Unit

The Combiner of Multi-Target Partial Plans, along with the connected plans (see Figure 1), completes the product holon largely discussed in Section 4. The role of the Combiner is to find the fastest escape route outwards, composed of only one path for each of Multi-Target Partial Plan. Following the example discussed in Section 5 (see Figure 4), the Combiner detects the path composed by the fastest route that leads the user to that window which can be reached and approached in the shortest time by the ladder truck. The detected Executable Plan is then plotted into the VRP and notified both to the endangered user and the rescue team. In this way, both of them can act coordinately towards the same intermediate point, exploiting the emergent collaboration and speeding the rescue operation. Assuming the user and the rescue team starting moving at the same time, the rescue operation lasts as the slower one. For this application path data about Multi-Target Partial Plans are exported into Excel (see Figure 5) to be elaborated. Obviously this process can be automated within the VRP in order to directly detect the viable Executable Plan.

7 Conclusions

The holonic management system, described in this paper, improves the usual emergency management approach, supplying more updated and significant information and investigating unusual solutions for rescue purposes in case of unforeseen events. In fact, the connection with BIM and sensors from the real world provides, in real-time, building’s topological information and contextual data. Furthermore, the resilient system, based on the holonic theory, makes it possible to tackle unexpected events by means of unconventional escape routes and support the standard rescue operations.

The developed system architecture, tested in a large mixed-use public building, shows its potentiality through the contribution given to officers in charge of emergency management. The detection of unconventional solutions in real-time helps, in an emergency scenario, to deal with urgent decision within a really short deadline.

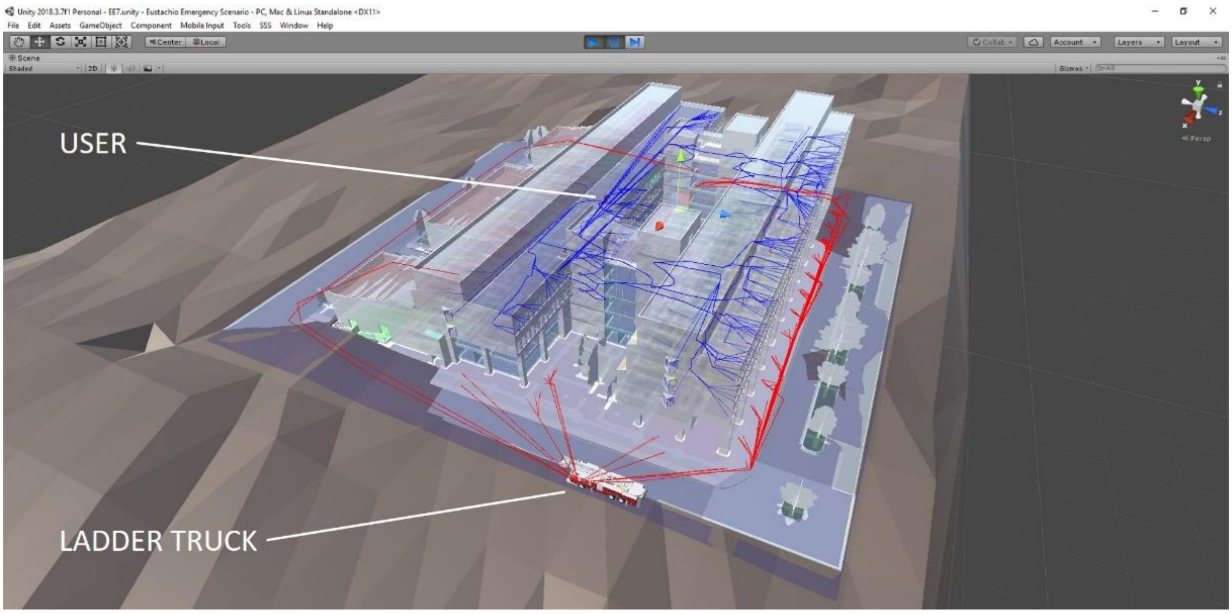


Figure 4. Generation of Multi-Target Partial Plans within the VRP using A*PPP

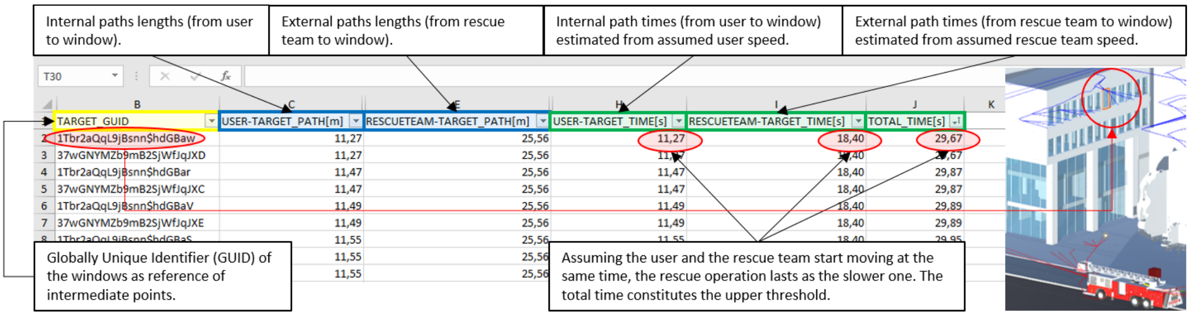


Figure 5. Processing in Excel of path data about the Multi-Target Partial Plans

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References

[1] Wang, S. (2009). Intelligent buildings and building automation. Routledge, ISBN: 0-203-89081-7.

[2] P. Valckenaers, H. Van Brussel, Design for the Unexpected, From Holonic Manufacturing Systems towards a Humane Machatronics Society, Butterworth-Heinemann, 2016, ISBN: 978-0-12-803662-4.

[3] Ulieru, M., Worthington, Paul. (2006). Autonomic risk management for critical infrastructure protection. Integrated Computer-Aided Engineering. 13. 63-80, https://doi.org/10.3233/ICA-2006-13105.

[4] B. Lane, New Civil Engineer (4.6.2018), available online (last accessed 10.12.2018): https://www.newcivilengineer.com/latest/grenfell-expert-report-cites-catastrophic-flaws/10031720.article.

[5] W.L. Grosshandler, N. Bryner, D. Madrzykowski, and K. Kuntz. Report of the Technical Investigation of The Station Nightclub Fire. NIST NCSTAR 2, National Institute of Standards and Technology, Gaithersburg, Maryland, July 2005.

[6] Koestler A., The Ghost in the Machine. The Macmillan Company, Hutchinson, 1967, ISBN: 0-14-019192-5.

[7] L. Wang, Azadeh Haghighi, Combined strength of holons, agents and function blocks in cyber-physical systems, Journal of Manufacturing Systems, 2015, https://doi.org/10.1016/j.jmsy.2016.05.002.

[8] P. Verstraete, B. Saint Germain, K. Hadeli, P. Valckenaers, H. Van Brussel, On applying the PROSA reference architecture in multi-agent manufacturing control applications, Multiagent Systems and Software Architecture, Proceedings of the Special Track at Net.ObjectDays, 2006.

[9] A. Giret, V. Botti, Holons and Agents, Kluwer Academic Publishers, Journal of Intelligent Manufacturing, 2004, https://doi.org/10.1023/B:JIMS.0000037714.56201.a3.

[10] Bonci, A. & Pirani, M. & Longhi, S. (2017). A Database-Centric Framework for the Modeling, Simulation, and Control of Cyber-Physical Systems in the Factory of the Future. Journal of Intelligent Systems. 27, https://doi.org/10.1515/jisys-2016-0281.

[11] RDF Ltd., IFCEngine DLL Library, available online (last accessed 9.1.2019): http://www.ifcbrowser.com.

[12] Microsoft Corporation, Introduction to ASP.NET Core SignalR (25.04.2018), available online (last accessed 15.3.2019): https://docs.microsoft.com/it-it/aspnet/core/signalr/introduction?view=aspnetcore-2.2.

[13] A. Granberg, A* Pathfinding Project, available online (last accessed 9.1.2019): https://arongranberg.com/astar/#.

[14] D. Soni, Introduction to Bayesian Networks (8.6.2018), available online (last accessed 8.1.2019): https://towardsdatascience.com/introduction-to-bayesian-networks-81031eeed94e.

[15] Bonci, A. & Pirani, M. & Cucchiarelli, A. & Carbonari, A. & Naticchia, B. & Longhi, S. (2018). A Review of Recursive Holarchies for Viable Systems in CPSs. Proceedings of the 2018 IEEE 16th International Conference on Industrial Informatics (INDIN), 37-42, https://doi.org/10.1109/INDIN.2018.8472055.

[16] Bonci, A. & Pirani, M. & Carbonari, A. & Naticchia, B. & Cucchiarelli, A. & Longhi, S. (2018). Holonic Overlays in Cyber-Physical System of Systems. Proceedings of the 2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA) 1240-1243, https://doi.org/10.1109/ETFA.2018.8502586.