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RISK COMMUNICATION AND AWARENESS OF THE BUILT ENVIRONMENT THREATENED BY DISASTERS WITH DIGITAL MODELS

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ABSTRACT

Natural and anthropic hazards are widely affecting the Built Environment causing damages and risks to the actual population and losses of architectural and environmental heritage to future generations. In particular, the potential value of historic city centres is threatened, both because of the intrinsic vulnerability of buildings and open spaces (squares, streets, and so on) and their high occupancy by inhabitants, tourists, students, workers, and other user profiles. Resilience of the Built Environment and human preparedness are two issues that have been addressing by really recent research and technical activities. Apropos, the objectives are to forecast and assess risks as well as to provide mitigative measures, including training programs for expert and non-expert people. In Risk management, communication is a fundamental step to reduce negative consequences of disasters. This is due to twofold purposes: 1) notifying those characteristics of the Built Environment that influence the mitigative/pejorative effects of hazard occurrence and 2) specifying safe behaviours to enhance users' knowledge and awareness, in order to be prepared to hazard occurrences. However, the latest scientific studies highlighted how the use of Digital Models, structured in info-graphic and parametric data, can support both the specific risk assessment and the fostering of risk communication, involving technical and common urban users. Digital Models for the risk assessment of Built Environment are part of current studies in the BE S^{2}ECURe project. Here, the identification of a double level of training (technical and pervasive) supported by Digital Models aims at supporting risk analysis and user awareness. In detail, the Technical Model results from interdisciplinary analysis based on multi-risk (Sudden and Slow Onset Disasters) data collection in order to study potential risks in the Built Environment; on the other hand, the Pervasive Model collects results of technical assessment and proposes structured information for user preparedness to risk. In this setting, the paper introduces the methodological framework for the creation of Technical and Pervasive Models underlying the respective goals within risk management and the first outcomes of its application to two selected case studies.

KEYWORDS: Risk management for Built Environment; Digital Models; Technical and Pervasive preparedness.

1. INTRODUCTION

Recent calamitous events demonstrated the high vulnerability of the Built Environment (BE) in cities exposed to natural and anthropic hazards. A more serious affection is represented by the historic parts of the cities where the risk level of Cultural and Historic BE increases with the high relevance of exposed Heritage and the inherent vulnerability of such buildings (e.g., state of conservation)[1]. Besides, such urban parts are also populated by multiple levels of users, including citizens and tourists, but also managed and safeguarded by technical and administrative personnel. The evaluation of BE elements that influence the vulnerability of the places represents the first step to study the criticalities to be overcome to protect places and users and propose mitigation measures.

Near to that, risk communication is part of the goals in increasing the BE resilience, constituting one of the last open issues to foster the awareness and the preparedness of all the urban users. Apropos, the SENDAI framework, built to define strategies for risk reduction, introduced as the first priority the understanding disaster risk for appropriate preparedness. The framework also reports specific actions to be implemented at national and local levels, starting the discussion with the effort to disseminate the collected data and practical information according to different classes of users. Besides, it proposes to develop, update and communicate disaster risk information, including risk maps, to decision-makers, the general public and communities in an appropriate format and freely available and accessible. Other relevant factors are the sharing experiences, lessons learned, good practices and training/education on disaster risk reduction addressed to build the knowledge of government officials at all levels, civil society, communities and volunteers, as well as the private sector [2].

Virtual Reality (VR) has been increasing its intrusion to cope with these scope and several sub-goals. In literature and current practices, VR is employed to study and propone correct evacuation responses and behaviour during an emergency, mostly investigated in buildings and infrastructure [3–6]. The benefits of VR-based training, world widely confirmed, are related to its immersive and participatory nature, the realistic quality of the environment, the possibility to reproduce large-scale real-life exercises with cost advantages. In addition, VR training can enhance consistency, quality and frequency of disaster training promoting asynchronous learning, also preparing users' readiness to self-perceived disasters [7].

In this framework, the use of Virtual Environments (VEs), based on parametric models (BIM-based) and panoramic images using VR technologies, can rise resilience assisting the risk managers (e.g., public authorities) with training actions for themselves and users. These VEs can work as Technical and Pervasive models with a double level of efficacy. Particularly, Technical models provide the implementation of Digital Models to determine risk indicators and risk maps with a parametric approach in risk assessment for disasters. Whereas, Pervasive models will help the dissemination of technical results, as well as behavioural education, for technicians and urban users, respectively. The enhancement of awareness and preparedness by means of such disruptive technologies are part of the BE S^{2}ECURe project, specifically applied for Open Spaces within Historic urban areas (H-OS).

Due to that, the paper introduces the methodological framework structured Technical and Pervasive Models based on a central VE that can share both in parallel sessions, including parametric Digital Models of H-OS (Section 2). Then, the approach is declined to seismic and terroristic events discussing parameters involved in the H-OS (Section 3) and finally, it shows the first application results based on two representative case studies (Section 4).

2. METHODOLOGICAL FRAMEWORK

Digital technologies provide multiple benefits within the process of risk management. They can create digital replicas of Historic Open Areas (H-OS), also sophisticated, to be employed for disaster-context simulations, risk assessment and potential modifications of the Built Environment (BE). In addition, digital material obtained by investigating the state of the BE against disasters can be disseminated within VE. In particular, the proposed method aims at 1) notifying those characteristics (discussed as parameters) of the BE that influence the mitigative/pejorative effects of hazard occurrence, and 2) specifying safe behaviours to enhance users' knowledge and awareness, in order to be prepared to hazard occurrences, mainly focused on Terroristic and Seismic Sudden Onset Disasters. At the basis of the risk assessment, risk parameters are identified and analysed in terms of their management within the communication levels to reach and considering their relations with single elements inside the H-OS as a space, related to the Buildings, as well as considering their mutual position within the H-OS (in the content or along the frontier).

For the paper scope, the workflow for risk communication is VR-centric, based on Virtual Tours (VTs), made up of spherical photos and hotspots, that assumes the role of database navigated via web [7]. VTs are created for both expert and non-expert users, because it is easy to be implemented and updated, working as a collection and organization of data with any specific aims in supporting simulations, and also managing extensive BIM models and 3D models, such as point clouds and texturized meshes, when available among the working group. In particular, this category of VE can be created with tools that are widely navigable thanks to web applications. This allows to have pervasive training that reaches everyone everywhere, against any criticalities caused by scarce interoperability among proprietary software products and applications' installation by non-expert users.

To reach the goals, the method (Figure 1) supports, firstly, the reconstruction of H-OSs, carrying out technical models for risk assessment and behavioural simulations using BIM and GIS models, respectively. Here, risk analysis and investigations about the intrinsic vulnerability of the BE.
Then, the sharing knowledge through VE based on VT, where spherical photos can be reality-based or BIM-based and are augmented with digital contents, and the point-clouds, the BIM model of the H-OS and results of behavioural simulations can be consulted. Specifically, the VE is analysed in order to reach a coherent representation of the H-OS elements and sharing their positive or negative effect on risks by colour mapping for technical and pervasive communication.

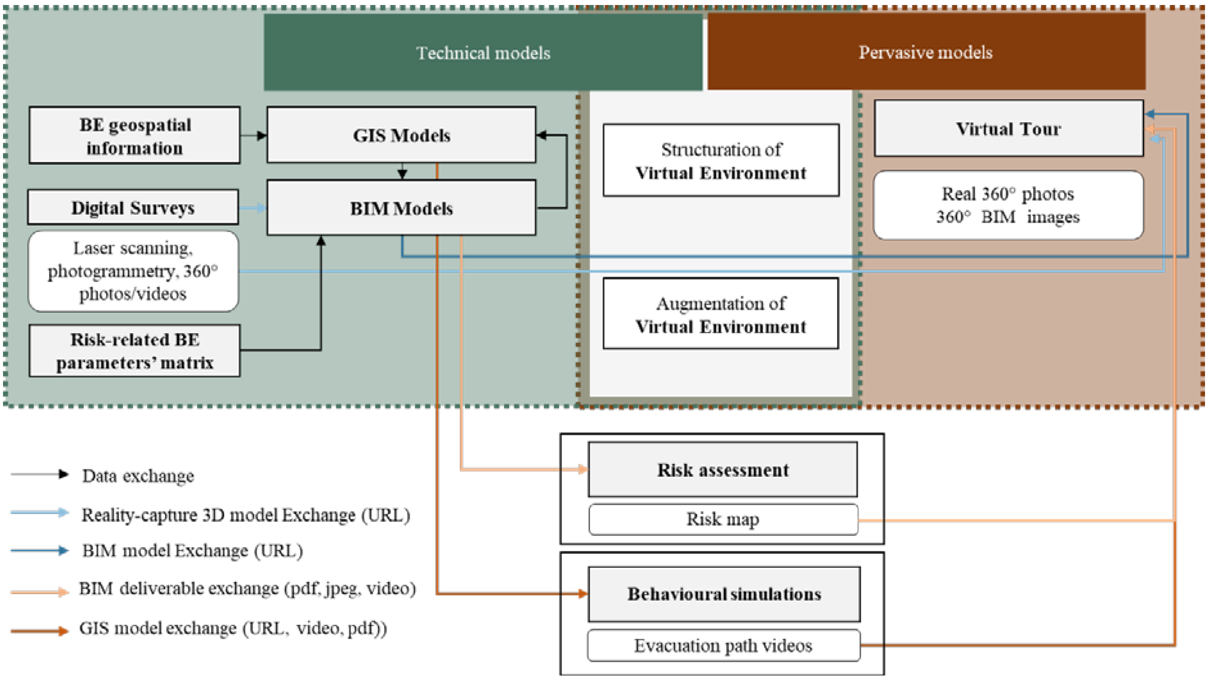

Figure 1: Methodological framework for risk communication and awareness.

As shown in the methodological framework (Fig 1), the construction of BIM models starts from the acquisition of preliminary BE geospatial information from GIS and, when feasible, using point clouds by laser scanning and/or photogrammetry for reverse engineering procedures. Considering the parametric model, geometric and information modelling workflow has been based on dual compatibility with the BIM and GIS environments. Specifically, both the geometric entities and the list of parameters were arranged according to 2D-GIS logic. After that, BIM modelling was performed to allow a straight-lined information to import back to GIS as the output of the workflow. Therefore, suitable elements and parameters for easy bi-directional conversion between 2D and 3D levels (i.e., based on point, line and surface) have been chosen. In this context, the Space category has been selected as the main synthetic repository to hierarchically inherit and store the H-OS content and frontier information. Therefore, risk parameters were preliminary selected based on multi-hazard combination associated with the case studies [8], in order to avoid confusion and over numbered information/data. Each parameter was catalogued into two main categories, based on the method to implement them in BIM environment: fillable by the users or computable through the software.

While, the VT tool for virtual training will be structured with parallel VTs about the BE with reality-based panoramas (*i* Sph_RGB) and BE mapped (*i* Sph_RM,r) according to the results of the risk assessment, consisting of i) reality-based panoramas mapped with hotspots (*i* Sph_RM,Real) or ii) BIM-based panoramas (*i* Sph_RM,BIM) with BE elements colour-mapped according to risk assessment, as alternative method.

Among the preliminary activities to build a VE (VT_RGB), the acquisition of the reality-based 360° photos/video (*i* Sph_RGB, i=1…n) to be linked each other with switch hotspots to re-create the H-OS (identified as LoR A). The *n* Sph_RGB represent and describe the BE elements visible in each scene.

In addition, icons for switch hotspots are selected to be easily read by users to move backward and forward within the tour and understand the available evacuation paths.

Another component of the VT is the orientation map to support orientation thanks to synchronized radars to the user's panning (LoR B). These floor plans can derive from different media contents, such as a Google map or a still image map, taken from GIS, CAD, BIM models or other image formats. The combination of LoR A and LoR B allows for the basic representation of the BE with its geometric, morphological and colour appearance. LOR B can effectively represent BE elements if the floor plan is created selecting a high level of detail, otherwise, LoR B is not sufficient for the representation. Nevertheless, additional information and description of the BE must be included within the VE through graphical information in detailed hotspots (LOR C). In this case, parameters are represented as digital content (image, pdf, and so on).

In this delineated framework, Technical and Pervasive models coexist to disseminate knowledge and consolidate awareness toward experts and non-experts. The VE provides authorized access to risk managers and public authorities to consult and share parameters involved in risk assessment and human behaviour simulations. While, open access parts of the VE communicate relevant results of the analytic activities to common users of the H-OS such as elements of the BE that concur positively or negatively to the risk evaluations and instructions for safe behaviour as evacuation paths.

3. ASSESSMENT OF RISK PARAMETERS

Identified parameters characterizing the BE are useful both for technical personnel and common users to reach a high level of resilience against seismic events and terroristic attacks, as two cases of natural and anthropic disasters. The first objective is addressed when employing properties in risk assessment and behavioural simulations to provide risk maps of H-OS and safe evacuation paths, within parametric tools such as GIS and BIM, that can be classified as Technical models. Nevertheless, the intrinsic peculiarities of the H-OS affecting the consequences of risks should be clear to the common users (inhabitants, students, workers, etc.). This characteristic of each building frontier and content should be communicated both for technical and pervasive purposes because it is a vulnerability of the BE.

Following previous results of the project in discussing the higher relevance of parameters involved in Seismic (S) and Terrorist (T) risks for their connection with inherent Risk affection and/or the study and assessment of evacuation paths [7–10], Figure 2 summarizes the contents. Particularly, parameters refer to the buildings (Bs) or to the H-OS discussing their negative or positive major affection (+/-) to S and T Risks, together with their option in representing within Technical and/or Pervasive models (Te/Pe).

BE classific.	Parameter	H-OS	Bs	Criteria of risk affection	Risk/s related		Risk com. level
					S	T	
S1_MAIN TYPE							
	Prevalent shape	x		Safe evacuation path (S-T)	+/-	+/-	Te/Pe
	Dimension	x		Safe Evacuation path (S-T)	+/-	+/-	Te/Pe
	H_{max} built front		x	Debris creation along evacuation path	-		Te/Pe
S2_CHARACTERISTICS OF GEOMETRY AND SPACE							
Frontier	Structural Type (SA/SU)		x	Technical vulnerability of walls	-		Te
	Accesses	x	x	Influence in exit "capacity" (S-T) Influence in attack "openness" (T)	+	+/-	Te/Pe
	Special buildings		x	Special mechanism of collapse (S) touristic attractiveness (T)	-	-	Te/Pe
	Town walls	x		Special mechanism of collapse (S) touristic attractiveness (T)	-	-	Te
	Porches	x	x	Special mechanism of collapse (S) touristic attractiveness (T)	-	-	Te/Pe
	Quote differences	x		Safe evacuation path (S-T)	-	-	Te/Pe
	Green area	x	x	Protection from attack (T+) Touristic attractiveness (T-)		+/-	Te/Pe
Content	Special buildings		x	Special mechanism of collapse (S) touristic attractiveness (T)	-	-	Te/Pe
	Fountain	x		Protection from attack (T+) touristic attractiveness (T-)		+/-	Te/Pe
	Monuments	x		Protection from attack (T+) touristic attractiveness (T-)		+/-	Te/Pe
	Dehors	x		Protection from attack (T+) touristic attractiveness (T-)		+	Te/Pe
	Quote difference	x		Safe evacuation path (S-T)	-	-	Te/Pe
	Archaeological sites	x		Protection from attack (T+) touristic attractiveness (T-)		-	Te/Pe
	Underground Park	x	x	Possible local ground damages (S)	-		Te/Pe
	Underground cavities	x	x	Influence on the frequency spectrum amplification of seismic waves (S)	-		Te/Pe
S3_CONSTRUCTIVE CHARACTERISTICS							
Frontier	Homogeneity of built environment age		x	Technical vulnerability of the frontier	+		Te
	Homogeneity of constructive techniques		x	Technical vulnerability of the frontier	+		Te
	Urban furniture/obstacles	x		Obstacles in evacuation (S – T) Protection from attack (T+)	-	+/-	Te/Pe
Content	Pavement lying	x		Safe evacuation path (T)		-	Te/Pe
	Urban furniture/obstacles	x		Obstacles in evacuation (S – T) Protection from attack (T+)	-	+/-	Te/Pe
S4_CHARACTERISTICS OF USE							
	Daily crowding	x	x	Exposure of the place	-	-	Te
	Sensitive target to terroristic	x	x	Attractiveness of the place to attacks		-	Te/Pe
	Vehicular accessibility	x		Influence of evacuation path (S - T) Accessibility to vehicular attacks (T-)	+	+	Te
	Pedestrian accessibility	x		Influence of evacuation path (S - T) Closeness to vehicular attacks (T-)	+	+	Te
	Type of users	x	x	Influence of evacuation path and behaviours	+		Te
S5_ENVIRONMENTAL CHARACTERISTICS							
	Type of infrastructures	x		Obstacle to the evacuation path	-		Te
	Permanent elements	x		Obstacle to the evacuation path	+		Te
	Hazard assessment	x		Inherent levels of hazard	-		Te

Figure 2: Parameters involved in Seismic (S) and Terroristic (T) risks, related to the H-OS or Buildings (Bs) discussed for their positive or negative affection (+/-) to the risks and risk communication levels as Technical and Pervasive models (Te/Pe).

As the S1 parameters regards the BE in its whole, the related detailed hotspot can be inserted in the Menu of the VE, instead of the Main View where panoramic scenes are. While, S2 contains properties specific for BE elements, thus the detailed hotspot is inserted on the top of the panoramic scene, where the BE element is located and recognizable. These reports could be edited with common writing software products or CAD/BIM/GIS software as exported sheets/schedules/drawings in *.pdf, according to software's availability within the working group. The *.pdf is selected as suitable digital content, that report text, images, URL, as it is readable independently from software and hardware. S3 properties can be detailed as *.pdf in a descriptive report that contains images and text, and this can be produced as described above.

The graphical information of constructive characteristics of walls, roof and horizontal structures could be provided adding a hotspot with URL of the BIM model that represents the wall stratigraphy and the roof/horizontal structure technology, per each identified Structural Unit of the built frontier.

As the S4 properties concern the OS or single BE elements, they can be managed with different procedures starting from the editing of specific reports about (*.pdf or pictures). In particular, the properties related to the whole OS are collected in documents the user can interact with through hotspot in the Menu of the VE. While, the characteristics of use about BE elements can be assigned in hotspots within the panoramic scenes where they are present. Other global properties about the OS, that can be managed with hotspots in Menu as descriptive sheets in *.pdf file, are the ones categorized S5.

4. IMPLEMENTATION OF TECHNICAL AND PERVASIVE MODELS

The two selected case studies for the application of the proposed methodology are Narni (Middle Italy) [N-S], with a high probability of earthquake occurrence (S) (level 2 medium-high, according to the national classification), and Trani (Southern Italy) [T-T] that has numerous vulnerabilities against terroristic attacks (T), for the presence of strategic and representative buildings (the Suevian Castle, The cathedral, the Courthouse).

In this research, two described methods for representing BE elements influence in risk assessment has been employed (i Sph_RM,Real and i Sph_RM,BIM based). One is based on reality-based spherical photos annotated with coloured polygons (red or green) to highlight the negative and positive factor, respectively. While the second method consists of the assignment of red or green colour to the material of the BE element modelled in BIM, according to its influence; consequently, BIM-based spherical photos has been exported to be used in Virtual Tour. Such methods are applied to the N-S and T-T, respectively, showing different levels of information and requirements to be showed and shared.

Considering the H-OSs with high probabilities and magnitude of seismic and terrorist events, Technical Models are enriched with parameters and information as reported in Figure 2, useful for risk assessment calculations in analytic models, such as customized BIM applications. While, Pervasive models based on Virtual Tours – addressed both for expert and non-expert users – may illustrate, in a user-friendly manner, each criteria and its positive/negative effect on the risk assessment. In both the applications, icons suggest practicable and denied evacuation paths.

Specifically, in [N-S] case, the *i* Sph_RM,Real about BE elements are created adding colored polygon hotspots on the parallel VT about seismic vulnerabilities (LoR A).

In Figure 3 some scenes are shown, for example the bell tower and Loggia dei Priori in Piazza dei Priori, Narni are annotated as elements of the BE that negatively affect the risk because they represent vulnerabilities. Indeed, the first building has the maximum height of the H-OS width, the second has a portico at the ground floor. They are vulnerabilities that experts and not-experts may know and be aware of because the overturning during an earthquake can create debris which block the evacuation and porticos is a weak point of the structure and potentially overcrowded. In addition, a report about building construction characteristics, in an image format .jpeg, is added to the polygon hotspot to be consulted by experts (a) (LoR C). The Technical models, such as BIM models reporting risk assessment outcomes and point clouds, can be navigated from the Menu, due to their possibility to be web-published in URL. In particular, the relevant parameters of each BE element, useful for risk assessment, are available clicking on the required BIM object (b) (LoR C).

Considering the application for the terroristic risk, Virtual models reports the parameters in Figure 2 using spherical images generated from the parametric 3D model. Specifically (Fig 4), the *i* Sph_RM,BIM reported in red material those obstacles that avoid a quick evacuation during a terroristic attack, as examples fences and parking area (a) (LoR A). The navigation of the entire BIM model is allowed, as in the previous application, in a dedicated Menu of the VE (b). Differently from the [N-S] case, the BIM model is accessible also in immersive VR, because it has been published via web with software products that allow this capability (LoR C). In particular, this method consents to activate a tour in the model to verify the passage of users in a space of maximum 60 cm among obstacles, according to the simplified approach in fire prevention standard. The parking area avoids the walk of persons between two cars because the space is less than 60 cm, confirming that the parking area has a negative effect on the evacuation in case of disaster.

This information is useful both for expert and non-expert users. The experts in risk management acquire knowledge about the BE in order to assess the risks and provide suitable mitigation measures.

While, non-experts – such as citizens, tourists, students, and so on – can enhance their awareness of BE and related risks to be prepared in occasion of events, having in mind the elements that are protective or dangerous.

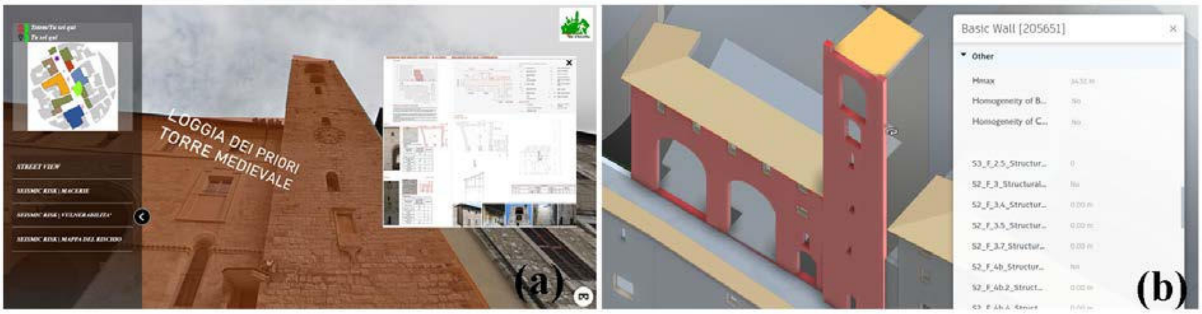

Figure 3: Application to the case study N-S for seismic risk; a) visualization of the VT, b) visualization of the digital content (BIM model)

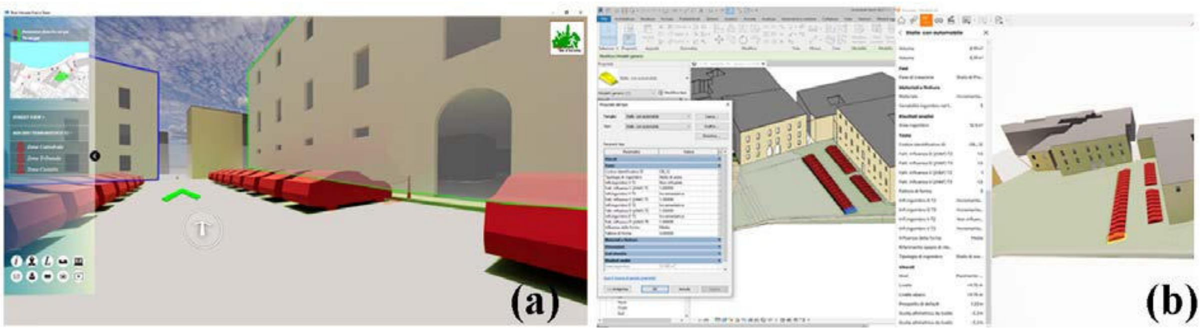

Figure 4: Application to the case study T-T for terroristic attack risk; a) visualization of the VT, b) visualization of the digital content (BIM model viewable in immersive reality)

5. CONCLUSIONS

Risk communication has a central role in increasing urban resilience. Innovative digital tools offer the opportunity to limit the gap between studies and dissemination purposes, both between technical practitioners and administrative and these with urban users. At the same time, such tools support the creation of shareable products using common platforms, maximizing the audience number.

The presented methodology demonstrates the good potentialities in using disruptive technologies for the communication and the dissemination of technical and pervasive contents in managing resilient H-OSs, in coherent and realistic threats. Specifically, the technical and pervasive tools under development are based on Virtual Tours, allowing the collection and sharing of common file formats like .pdf and .jpeg, as well as three-dimensional models such as BIM and point clouds, interacting by means of URL and allowing a smart management of data (usually non fully referenced to the places) and actual representation tools requirements (e.g., BIM modelling for the Public Buildings).

These features generate several advantages:

- The use of parametric models to support the technical knowledge helps practitioners in managing and understanding the relations between the parameters involved for single risks, as well as their relevance in the choice of mitigative solutions.
- due to the possibility to create spherical acquisition, the perception of the place can be maximized for common users, in addition to the use of friendly risk maps (based on colour scale). However, the potential higher educative level requires to be verified after the sharing phase.

Thus, the resulting Virtual Environments about each developed case study can be also interconnected in a web(3D)GIS platform based on 3D city models and CityGML standards, preparing the basis for multi-risk scenarios databases to be simply shared as best practices for other common cases.

All these potentialities will be tested in future developments of the project, mainly for the assessment of the real educative level that should be reached, also implementing the behavioural results and simulations to such static and augmented models.

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