On the usage of Virtual Reality for Crisis Management exercises in Critical Industrial Sites

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ABSTRACT

EGCERSIS is a starting research program aiming at defining a virtual collaborative training space for crisis management. It should provide the users (first and second aid, firefighters, etc.) with a way to virtually perform operational and strategic tasks of crisis management in digital twins of critical infrastructures. The training system is structured according to four main components: (i) protocol and tools for digital twins generation, (ii) scenario editor dedicated to defining crisis use-cases within the modeled digital twins, (iii) integration with the technological crisis management platform (RIO-Suite), and (iv) monitoring component in charge of the continuous edition of dashboards (real-time and afterward). The main expected benefit of the EGCERSIS program is to create a breakthrough in the way training and exercises are performed in critical sites.

Keywords

Virtual Reality, Training, Coordination.

INTRODUCTION

Critical sites are of various types. In this article, it is considered that the word “critical” refers to the impact of a failure of a considered *system* on the capacity of the whole human *territory* to keep on performing its missions (e.g. first necessity supplying, protection, energy providing, water, health care system, etc.) as stated by some measure of performance (Stewart, 1992). The *territory* is a geographical space that covers the spatial extension of a government’s jurisdiction (Gottmann 1975). The *system* concerns a critical site that is located in the considered territory. For instance, the system may refer to a power station, a production system, a supply chain, a transport infrastructure, or a health care system (Yodo and Wang 2016).

These critical sites are legally obliged to perform training exercises to prepare for any crisis situation within the infrastructure itself. These exercises can be set up twice a year, once a year, every two years, or more or less frequently depending on the criticality of the considered system and the legislation of the considered territory.

However, setting up such an exercise is quite a complicated task, enacting the planned exercise is a difficult task too, and exploiting the results of the exercise in a productive manner is complicated as well. All these elements make crisis exercise a time and resource-consuming task with low benefits. It is a regulatory, mandatory and necessary activity which is nowadays neither effective nor efficient. The EGCERSIS research program believes that the use of virtual reality (VR) may break the barriers and reduce almost all drawbacks mentioned. This

might be a huge and significant giant leap forward in the domain of preparation (on an efficiency point of view and even on a legal point of view).

This article is structured according to the following sections: first, an overview of the context, expectations and related work is presented. Then the functional architecture of the whole virtual training system is described. Finally, the next steps are listed with perspectives as well.

CONTEXT OF THE EGCERSIS RESEARCH PROGRAM

This section aims at defining the main objectives of the EGCERSIS program. One key challenge is to identify the pros and cons of the EGCERSIS approach (based on VR) compared to the use of classical real size exercises.

The location of the EGCERSIS research program

The very classical vision of crisis management includes the following phases: *prevention*, *preparation*, *response* and *recovery* (Atlay and Green, 2016) as shown in Figure 1. The preparation phase is one critical phase for the efficiency and the effectiveness of crisis management (and especially for the efficiency and effectiveness of the response phase). If the prevention phase aims at trying to avoid the use of the response phase (by preventing the occurrence of the critical events), the prevention phase aims at supporting the response and making it as efficient and effective as possible (by setting up all the necessary resources and processes basically).

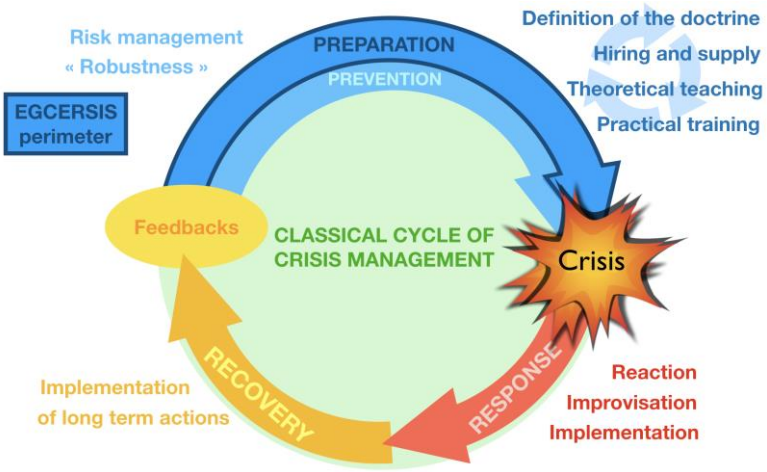

Figure 1: The location of the EGCERSIS research program in the classical cycle of crisis management

During the preparation phase, specifically in the case of critical industrial sites, there are several tasks that must be performed (**Erreur ! Source du renvoi introuvable.**). First, the doctrine must first be defined. On a practical point of view, this step concerns the definition of internal and external action plans. Then, the question of resources (human and equipment) must be considered in terms of availability and appropriateness, which concern hiring and supply. Thirdly, there is a step of theoretical training, before the fourth step of practical training. The theoretical training is more about "know" while practical training is more about "know how". In the preparation phase, the EGCERSIS program focuses on the practical training step, including exercise definition, enactment, and improvement.

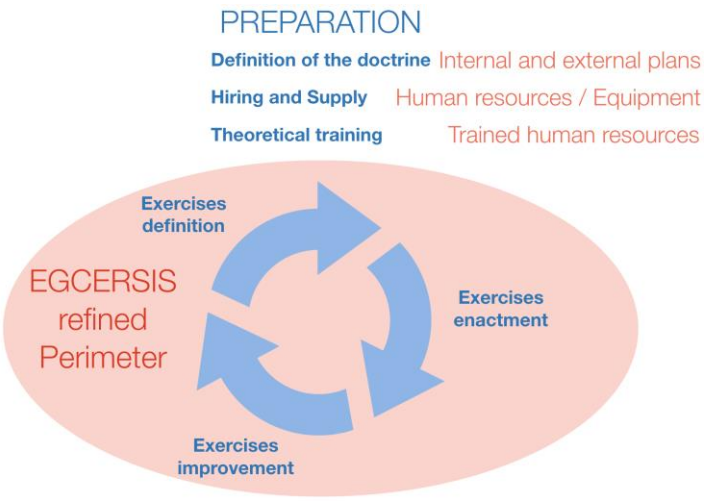

Figure 2: The refined location of the EGCERSIS research program in the Preparation phase for critical sites

The reason why the EGCERSIS research program focuses on those steps (definition, enactment, and improvement of exercises) of the Preparation phase is mainly due to the fact that these steps are the less efficient ones. This part of the preparation truly requires a concrete breakthrough to overcome the current limitation training exercises.

The limitations of training exercises

In Europe, the SEVESO[1] industrial sites are required to conform to a set of measures related to their risks. Usually, it implies to define internal plans (describing the organizational measures set up to deal with *alert*, *evacuation*, *treatment* ...) and external plans, if necessary (similar to the internal plans but dedicated to the wider impacted perimeter of the site). Besides, it is usually mandatory to run exercises dedicated to implement the internal and/or external plans and to practice the activities of first aid actors (in contact with the event), second aid (people on site trained to intervene on the event) and institutional responders (e.g. firefighters).

However, these exercises have generally a lot of drawbacks. Basically (Ardila, *et al.* 2013) summarizes the main issues: "(i) traditional training simulated-based systems are expensive and offer little flexibility (e.g. it is not possible to simply burn up a building every time a drill is carried out); (ii) real training in the field of emergency management is very expensive and complicated regarding the harmonization of procedures between agencies". More precisely, the following identifies specific drawbacks in the context of the program.

During the preparation of the EGCERSIS research program, interviews have been made of five local safety and security directors of critical industrial sites about the efficiency and effectiveness of real-size crisis management exercises in their organizations. Though there are obvious benefits and these exercises are mandatory on a legal point of view, the interviewed professional described jointly the same kind of limitations and drawbacks of the current way of managing the preparation phase of these critical sites mainly with real-size exercises. Basically, their vision can be discomposed according to the two dimensions presented in Table 1: columns represent the lifecycle of an exercise (*definition*, *enactment*, and *improvement*) while lines represents the expectations of an exercise, *i.e.* the need for participants to learn appropriate reactions and processes (*short term impact*), to remember these reactions and processes (*long term impact*), to be as many as possible to benefit from the exercise (*inclusiveness*), to be trained by the exercise on a various range of scenario (*coverage*).

Table 1. The limitations of real size exercises in critical sites

	Definition	Enactment	Improvement
Short term impact **Does the system learn something beneficial?**	• The light manpower that can be dedicated to the definition of the crisis scenario.	• The poor realism of the exercise due to the lack of special effects and real damages.	• The lack of concretely exploitable, significant, and capitalizable data except for some pictures and movies

[1] The **Seveso directive** is the generic name of a series of European directives ruling the management of industrial sites that present major accident risks (so called SEVESO sites).

	• The lack of support equipment (only maps and plans) to create relevant exercises.		(in the best case).
Long term impact **Will the system remember what has been learned?**	• The difficulty to plan an exercise with the objective of making it a long term benefit, considering that this objective may seem secondary with regards to short term impact and relevance of the scenario.	• The low frequency of these exercises due to the actual disturbing impact on the site.	• The difficulty to mobilize the workforce after the exercise considering their impression of loss of time. • The lack of concretely exploitable, significant, and capitalizable data except for some pictures and movies (in the best case).
Inclusiveness **Are all the people that should be included, actually included?**	• The difficulty to expect a large "official" mobilization of the workforce considering the actual disturbing impact of such an exercise on the site.	• The practical difficulty to explain the scenario to a lot of people and to have them commit all together in it. • The low involvement of people due to the weak sensory impact of a simulated exercise on themselves.	• The difficulty to set up a transversal feedback process to generate "lessons learned" and "significant benefits" on as much as possible sectors of the organization.
Coverage **Are all the scenarios that should be studied, actually studied?**	• The hard limits for the scenario that can be designed due to the fake aspect. • The complexity of including as many dimensions as possible in a one-shot realistic scenario.	• The low frequency of these exercises due to the actual disturbing impact on the site. • The complexity of running "live" a scenario that would include as many features as possible.	• The complexity of a fruitful analysis of the exercise with regards to all the relevant dimensions that should actually be considered.

In a nutshell: (i) mobilizing concerned actors is difficult, (ii) designing realist and fruitful scenarios is difficult to obtain, (iii) completeness, or at least a covering variety of scenarios is difficult to get, principally because of the low frequency of such exercises, (iv) implication of human beings, and the impact on them is deeply varying, and even unpredictable (Dolidon, 2018).

Related works on the use of Virtual Reality with regards to classical real size exercises

The use of Virtual Reality in crisis management has been studied a lot in the last twenty years, from its appearance to its current maturity. Basically, previous related research works have identified the pros and cons of the usage of VR:

- Identified advantage: Most authors mention the benefit of VR on a realistic point of view: "*Virtual reality is a powerful technology for creating a sense of immersion and 'intelligent' virtual characters have recently been integrated into virtual worlds for the purpose of training*" or "*the virtual environment will allow trainees users to gather all the necessary visual and auditory contextual information to make the necessary decisions*" (Dugdale, et al. 2004). The flexibility is also another positive point mentioned: "*Virtual Simulation's greatest advantage over traditional planning processes is that there is no pre-established model or hard-coded rules to follow.*" (Hendela, et al. 2006) or "*Virtual Simulation provides flexibility and ease of preparation while stimulating creative and critical thinking.*" (Hendela, et al. 2006) or "*Replicability; scalability and adaptability, testing of new technologies*" (Berndt, et al. 2018). The last main point concerns the price: "*The use of 3D virtual environments for conducting training exercises can provide numerous advantages such as flexibility, relative low cost given a midterm horizon and large scenario development capabilities.*" (Zarraonandia et al. 2014) or "*a network-based system that integrates reality and simulation will be, on the one hand, relatively cheap because all expenses that real in-site training entails (such as moving many people, vehicles) are reduced and, on the other, will facilitate the interoperability and harmonization of procedures between agencies.*" (Ardilla, et al. 2013). Finally, some authors also mention the safety aspect of using VR: "*In contrast with exercises on site, there is little if any danger to the paramedics in a VR simulation. Mistakes can be made without adverse consequences, allowing for experimentation and learning by experience. Because of safety requirements on site, some risks can be presented in an even more realistic way in VR simulations (e.g., fire, explosions, toxic gas).*" (Berndt, et al. 2018)

- Identified disadvantages: One major point concerns the lack of interactions: "*Although many virtual environments strive to offer realism in their simulations of weather, population, and incident happenings, they often fall short in terms of collaboration among simulation participants: unless participants are at the same physical location, their ability to see and interact with one and other is limited.*" (Wright, et al. 2008), or "*interactivity that is possible may not be truly synchronous*" (Wright, et al. 2008) or "*such systems […] use simplistic models of cognitive behavior and emotion to simulate intelligence, and usually only allow one user at a time to participate in the training scenario.*" (Dugdale, et al. 2004). Even if the two articles are quite old, the multi-player aspect is still an issue for deep interaction. Another point concerns the difficulty to implement such systems: "*However, the adoption of 3D virtual environments, in practice is not as widespread as might be expected due to the difficulties associated with their design and development.*" (Zarraonandia et al. 2014) or "*such systems typically require huge computational resources*" (Dugdale, et al. 2004). Finally, they are also some drawbacks regarding the completeness of the sensations "*it does not allow users to obtain the necessary tactile information (e.g. physical contact was used between trainees to reinforce a verbal message or to initiate an action)*" (Dugdale, et al. 2004) or simply the question of virtual reality sickness "*lack of the same physiological stimulation, the longstanding problem of possible simulator sickness and the lack of tactile feedback and "hands-on" experience of real-life exercises*" (Berndt, et al. 2018).

Finally, the conclusion that can be suggested, based on the previous elements, is that VR presents a lot of significant advantages (especially compared to classical exercises). Besides, most of the identified disadvantages are due to its newness. Both these statements make it a very good candidate for a tangible and meaningful innovation: a lot of good points that may contribute to a breakthrough and several bad points that should be corrected with the technological improvements.

The objectives of the EGCERSIS research program

From the two previous subsections regarding limitations of real size exercises and benefits of Virtual Reality, the EGCERSIS research program has been defined according to the following main objective: providing security managers with a framework dedicated to preparation and training for crisis management on critical industrial sites. The idea is to cross virtual reality and decision support in an uncertain environment. The virtual training environment should provide two main features:

- An immersive experience in the digital twin of the critical industrial site in order to experiment with the predefined scenario and prepare intervention teams (first aid, second aid, external responders, etc.). This will result in the creation of a twin of the site in VR, where the participants will be able to evolve thanks to VR goggles, and where they will be confronted to the predefined crisis scenario.
- Monitoring and supervision tools to support the virtual exercises and to generate useful and actionable real time and later reports to understand and capitalize on the played exercises.

These two main features will be implemented through four main components:

1. The exercise editor (dedicated to site modeling and scenario definition)
2. The virtual environment (dedicated to multi-player scenario enactment).
3. Decision support tools (dedicated to accompanying decision makers of the crisis cell).
4. Dashboard tools (dedicated to *in situ* and *a posteriori* analysis of players, exercise and plans).

These components and the provided features should tackle the limitations previously identified in Table 1, as shown in **Erreur ! Source du renvoi introuvable.**:

	Definition	Enactment	Improvement
Short term impact **Does the system learn something beneficial?**	• The light manpower that can be dedicated to the definition of the crisis scenario. • The lack of support equipment (only maps and plans) to create relevant exercises.	• The poor realism of the exercise due to the lack of special effects and real damages.	• The lack of concretely exploitable, significant, and capitalizable data except for some pictures and movies (in the best case).
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Figure 3: The contributions of each of the four components on the limitations of real size exercises in critical sites

Basically, the previous figure shows that two components are more dedicated to the *definition* step (the *Exercise editor* and the *Virtual environment*), two are more dedicated to the *enactment* step (the *Virtual environment* and the *Decision support* tool), and finally one is more dedicated to the *improvement* step (the *Dashboard*).

OVERVIEW OF THE EGCERSIS RESEARCH PROGRAM

In this section, the architecture of the EGCERSIS platform is introduced more precisely.

The main scientific and technical obstacles of the EGCERSIS research program

Considering the objectives and associated components described in the previous section, the following barriers have been identified and must be considered by the EGCERSIS research program:

- Obtaining a relevant, trustable and continuously updated digital twin of the considered critical industrial site is absolutely mandatory and should be considered as an absolute requirement. Obviously, these digital twins should, in addition, be exploitable by the Virtual Reality environment (based on the Unity® framework[2]) chosen for the research program.
- Crisis management is, by essence, the world of the unexpected. More than anywhere else, instability is the norm. As a consequence, it should be possible for users, not only to define as various scenarios as they want (type of crisis, kinetics of the crisis, nature of the crisis, etc.) but also to intervene during runtime to change or update the scenario in order to optimize the training exercise. So, this is not only a question of the flexibility of the exercise editor (which is though crucial) but also a matter of dynamicity and openness of the Virtual environment.
- Moving crisis management training from the real world to the virtual world should not only include actual and current practices but also tools and technologies. As for example, if a communication, mapping or planning tool is the nowadays' reference in the world of responders (first aid, second aid or external), it must necessarily be integrated into the virtual world to optimize the training session.

[2] https://unity3d.com/

- The multi-player aspect is an unavoidable feature. It is so significant in the real world, where crisis management is foremost a collaborative issue, that it must be precisely and efficiently integrated into the virtual training platform. Besides, this collaboration aspect should cover on the one hand the human aspect (between two or more persons) and the service aspect (between two or more organizations).

Big picture of the EGCERSIS research program

To tackle the obstacles described in the previous sub-section, the EGCERSIS research program aims at performing the four main following steps as presented in Figure 4:

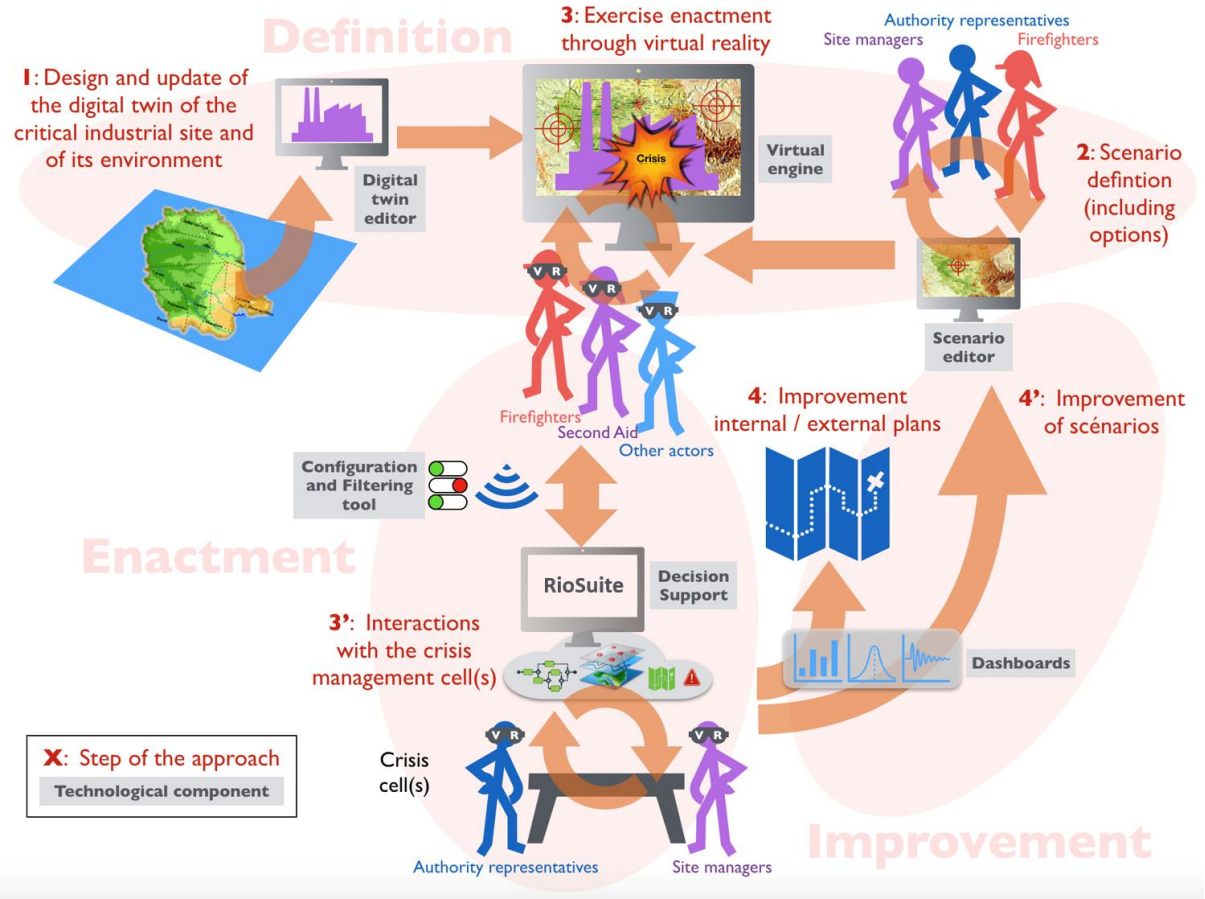

Figure 4: The big picture of the EGCERSIS outputs

1. Based on actual plans of the building (for instance the ones generally dedicated to being constantly updated in the crisis management plan of a SEVESO site) and on other inputs (crowdsourced map, private map, UVA, etc.) a 3D digital twin of the considered site should be defined within the dedicated editor.
2. The selected scenario and its characteristics (nature, timeline, kinetics, etc.) should be described in the dedicated scenario editor. This editor is to be used by authority representatives, site managers or responders. It should permit to create and implement a realist and adaptable crisis scenario. The idea would be to choose and implement a crisis scenario in a virtual reality digital twin of a chosen industrial site. One envisioned possibility is to be able to make the scenario evolve depending on the answers of the stakeholders who are solving the crisis.
3. Immersed in the virtual environment (through VR goggles), all the potential stakeholders (first aid, second aid, firefighters and other responders) do face the scenario and do experiment the exercise in a realistic environment as close as possible to the real site. Meanwhile, the crisis managers do deal with the crisis situation, using RIO-Suite as support for their decisions (RIO-Suite receive data directly from the simulation environment, filtered by a configuration panel presented in the perspective section).
4. Due to the numerical nature of the exercise, everything about the exercise and its dynamics may be

collected in real time. This is an amazingly positive point because it means that everything could be monitored and even replayed on demand to analyze, visualize and exploit the exercise. This should allow on the one hand to improve the exercise but of course, on the other hand, to improve the plan as a whole (including the skills and know-how of the people).

PERSPECTIVES OF THE EGCERSIS RESEARCH PROGRAM

From the point of view of the EGCERSIS research program, the potential results of the program would lead to a revolution in the domain of security and safety of industrial critical sites. Roughly speaking, the *frequency*, *quality*, *realism*, *coverage*, and *exploitability* of exercise could simultaneously be increased. This is definitely a very promising avenue for the improvement of (i) internal/external plans and (ii) efficiency/effectiveness of actors involved in crisis management (first and second aid as well as external responders). Such an improvement of the preparation phase of such critical industrial sites would consequently improve the resilience of the industrial system impacted. This perspective is clearly the most important of the EGCERSIS research program. Besides, it opens a full business market for Virtual Reality companies.

Another interesting avenue of the EGCERSIS research program is the possibility of having the virtual environment used for evaluating, testing, practicing not only plans and processes, but also new tools and new technologies. Actually, the virtual nature of the played exercise allows considering exploiting absolutely any type of data generated by the virtual environment. Thus, it would be of great benefit to check if the indoor geo-location of responders (which is a very trendy expectation that could completely and perfectly be simulated in the context of a virtual exercise) would help considerably or marginally crisis management. Similarly, it could also be very interesting to plug any new technological platform to the virtual environment (through a configuration and filtering tool, as presented in Figure 4, dedicated to simulating which data should actually be transmitted to the evaluated platform). For instance, within the EGCERSIS research program, it is planned to create and evaluate a new version of RIO-Suite. This version of RIO-Suite would be based on a virtual environment as well and would allow the decision makers to move in a virtual environment where the visualization and the decision-making would be easier. In this context, the configuration and filtering tool would be in charge to simulate what kind of data RIO-Suite should actually be fed with. The kind of data that RIO-Suite is able to use is presented in (Benaben et al.). The very interesting point is that all the data could entirely be obtained through the virtual environment.

The last perspective considered in this article concerns the extension to other exercises than the one in critical industrial sites. This first target is mainly due to the fact that these sites are legally obliged to run crisis management exercises and have consequently all the required material (plans, maps, scenarios, etc.) and a lot of interest for the EGCERSIS research program. However, if the process becomes seamless and effective, if the benefits are obvious and if the efficiency of preparation is clearly demonstrated, other sites could be considered: critical infrastructure (airport, train station, etc.), overcrowded site (touristic place, public building, university, etc.) and any place that potential users (responders but also homeland security stakeholders) would like to study.

CONCLUSION

The EGCERSIS research program is dedicated to creating a breakthrough in the way crisis management exercises are conducted. This domain of the *preparation* phase definitely suffers from a lack of effectiveness and efficiency. For years now, the classical yearly exercises, with simulated imaginary damages and casualties, have shown how disappointing they can be. These exercises, even if most of the time mandatory, are really far from the results they should bring. As a consequence, the *response* phase which is supposed to be a combination of a majority “implementation of the results of the preparation phase” and a minority “improvisation due to the specificity of the faced situation”, can often be considered as a majority “improvisation” and a minority “implementation”. Virtual Reality opens completely new perspectives: allowing, on the one hand, to replicate the real world to perform experiments in real size without any barriers, and on the other hand to forget about the real world in order to create completely free interfaces benefiting from the realistic physical environment but independent from the constraints of the real world. This new world of VR should be investigated with both these visions.

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