SCIRES-IT
SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 2, Issue 1 (2012), 133-148
e-ISSN 2239-4303, DOI 10.2423/i22394303v2n1p133

# INTERACTIVE VISUALIZATION OF CROWDS FOR THE RESCUE OF CULTURAL HERITAGE IN EMERGENCY SITUATIONS

*Marcello Carrozzino*[*], *Veronica Piacentini*[*], *Franco Tecchia*[*], *Massimo Bergamasco*[*]

[*]PERCRO, TECIP Institute, Scuola Superiore Sant'Anna, Pisa (Italy)

**Abstract**

Vulnerability of cultural properties can be significantly reduced through specific disaster plans, focused on safeguarding cultural assets in emergency situations. The effectiveness of these plans may be enhanced by the use of innovative technologies for visualization and verification purposes. In this paper we propose an alternative application of the dynamic simulation of large crowds for emergency planning in open spaces. We argue that applications related to the real-time simulation and visualization of crowds might be used also for cultural heritage risk preparedness. The application we propose aims to highlight the need of designing different paths for different goals. In an emergency plan related to cultural assets, crowd dynamics simulation could be used to plan different routes with specific functions: paths for evacuating visitors, and paths for evacuating object. Based on the identification of the first ones, which represent the main priority, the second ones can be designed, as alternative and complementary routes allowing cultural heritage operators to immediately take part in emergency operations and to work over objects salvage actions, without obstructing people salvage or escaping activities.

An evaluation of the application of such techniques is reported, with the experimental validation of the behavioral model and the related simulation planned as future work. A possible application of this technique for training operators is also outlined.

**Keywords**

Virtual Reality, Crowds Simulation, Cultural Heritage, Real-Time Graphics

## *1. Introduction*

Cultural Tourism is nowadays a common phenomenon to be carefully considered in order to prevent tourists behaviour from being dangerous to cultural assets, especially in the context of critical scenarios, such as natural or manmade disasters. For a better integration of tourism and heritage’s interests, comprehensive tourist development plans have been already considered essential[1] (Canterbury, 1990). In order to protect cultural properties adequate measures, such as the increase of surveillance, the special protection of sensitive parts, the organization of one-way walking circuits, have been or are intended to be adopted. This paper focuses on the importance of implementing emergency plans to rescue cultural assets, addressing issues coming from the presence of tourism and overcrowding in general.

---

[1] Resolutions adopted by the conference Heritage and Tourism. Canterbury 27th-30th March 1990, point 3.1

## *2. Previous Work*

In case of a disaster, mass panic is likely to occur during and immediately after the catastrophe. In this case there are risks of mass-casualty incidents caused by crushes, rushes and crashes (Alexander, 2002). Therefore, particular attention should be put to interventions aiming to support evacuation processes, which fall in two categories: at the level of the infrastructure (e.g. design appropriate barriers and escape routes), and at the organisational level (e.g. design plans for emergency rescue) (Zarboutis, 2005). Especially where structural measures are not feasible or adequate to address the problem, emergency planners should direct their attention to non-structural procedures.

A correct analysis of crowd behaviour is an important requirement for the drafting of a functional emergency plan (Lindel, 1991). Numerous studies about Crowd Dynamics (Loscos 2001) have been carried out with the intent to understand and reproduce the behaviour of real persons in such situations (Ulicny, 2001). In order to be effective, the plan should consider both technical and social components of warning and evacuation systems. Technical components involve a variety of things, including the use of technology. Social aspects refer to factors influencing how people perceive and interpret warnings (Streeter, 1991). Both technical and social components of the system are important because failures can occur everywhere.

Previous investigations carried out in the field of emergencies involving crowd dynamics (Hanna, 1994), mainly focus on saving human beings. Although naturally this always represents the first priority in an emergency plan, it is not the only one. Similar studies can be also adapted to define emergency plans for safeguarding cultural assets, using crowd dynamics analyses for the individuation of alternative paths addressed to cultural operators taking part to the emergency procedures and to operate simultaneously with other emergency teams. It is important to keep in mind that emergency services (like Fire Departments, Police, or Civil protection Department) first order of business is to save life and they may not be sensitive to the contents of that structure, unless they are informed of its value. Special cultural heritage emergency team can mean the difference between total loss of collections and only minimal damage (Podany, 1997). For this reason museums or institutions staff, curators, directors, security guards must be involved in the process of actualizing plans. While National, State and Territorial network is concentrated on acting into the emergency, Historic site or Museum preparedness groups should take responsibility for protecting the property, working in coordination with local emergency services, preservationist and related professionals (Nelson, 1991).

## *3. Emergency Planning*

The main scope of emergency planning is to reduce risks and damages. Plans cannot be improvised during emergency; they must be developed before an event strikes as a mitigation measure, and put into effect during or immediately after its occurrence, as a form of preparedness (Alexander, 2002). Evacuation processes cover a different role depending on the kind of risk encountered and the state of technology used. They can be considered an effective pre-impact tool for reducing danger, especially when it is possible to obtain an accurate prediction or detection of the threat, as in the case of flood caused by typhoons or heavy rain falls. However, they can also be considered a post-impact measure when predictions are not feasible, as we learn from earthquakes (Lindell, 1991).

When considering cultural assets, especially when they are well known due to their artistic or symbolic value, tourism has to be introduced into the emergency plan as cause of overcrowding and, consequently, of potential risk. Therefore, in case of emergencies, managing crowds may become an important priority. Generally emergency plans aim to put into effect the complete evacuation of human beings or cultural objects from the threatened area. Lives can be saved if people are appropriately warned about the impending disaster, but they must also respond to the warning in the opportune and timely manner. Safeguarding cultural objects, in the same way, depends on the respond to warning of cultural operators and volunteers involved in salvage actions. To make possible the coexistence of emergency procedures for evacuating human beings and salvaging cultural properties, the valuable parts of sites, buildings, collections or objects should be indicated as an essential part in the general emergency plan. For instance, detailed plans of an historic building must provide[2]:

- access routes
- emergency exits
- water points (hydrants, fire-points, etc.)

---

[2] Federal Office for Civil Protection. Protection of Cultural Property against Disaster. Annex n. 1: Precautions. Guidelines for the Preparation of a Disaster Plan.

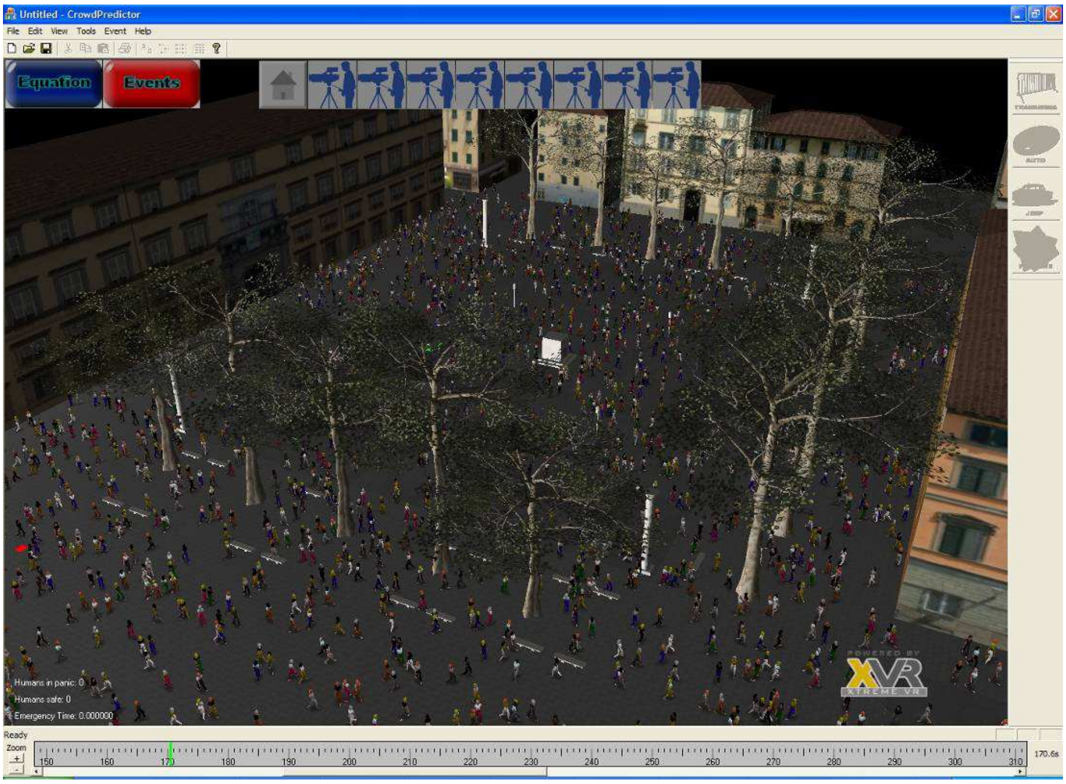
- location of manual fire extinguishers
- location of electrical distribution of fuse boards
- location of the alarm panel (with information on how it can be turned off)
- location of the collections (inventory lists with order of priorities, storerooms)
- whereabouts of packing materials and moving equipment
- evacuation routes

Vulnerability of cultural properties can be significantly reduced through specific disaster plans, focused on safeguarding cultural assets from natural or man-made disasters. It is worthy to consider that in these circumstances a higher level of complexity is introduced, as we have to deal both with visitors and cultural heritage risks. The effectiveness of these plans may be enhanced by the use of innovative technologies of visualization and simulation. Focusing our attention on the individuation of access and evacuation routes, we argue that ICT applications involving the simulation of crowds for drafting evacuation plans (as in (Helbing, 2001, and Xiaoping, 2009) can be utilized also for cultural heritage risk preparedness. The application we propose, based on the above mentioned studies, aims to highlight the need of designing different paths for different goals. In an emergency plan related to cultural assets, crowd dynamics simulation could be used to plan different routes with specific functions: (i) paths for evacuating visitors, (ii) paths for evacuating objects. Based on the identification of the first ones, representing the main priority, the second ones may be designed, as alternative and complementary routes allowing cultural heritage operators to immediately take part in emergency operations and to work over objects salvage actions, without obstructing people salvage or escaping activities.

Assuming different kind of crowds phenomena, corresponding modelling techniques have been identified, ranging from considering the crowd as a unique entity whose behaviour is simulated by means of statistical data, to the detailed simulation of each individual, in order to introduce in the investigation factors related to the interaction among persons and with the surrounding environment. Another distinction may be made on the basis of real-time features, with consequences on the trade-off between the accuracy of the simulation and the system reactivity to ad-hoc user-introduced perturbations to the flow. Additional issues related to computational overload must be taken in account when dealing with real-time applications, particularly if a realistic 3D visualization is required.

## 4. *Virtual Crowds*

As a case-study we developed a software application (Crowd Predictor) which allows simulating and interactively visualizing the behaviour of crowds in emergency situations, applied to the case of planning the evacuation of a square, Piazza Napoleone in Lucca (Italy), usually scene of large scale events, simulating several types of possible emergencies.



Humans in panic: 0
Humans safe: 0
Emergency Time: 0.000000

**Fig. 1:** Crowd Predictor for Piazza Napoleone in Lucca

The application is meant as a tool for analysis and prevision upon public events participated by large amounts of people. Through the geometrical description of the spaces where the crowd is contained, of the obstacles which hamper the free passage, and a basic description of some "emergency generators", the system evaluates, on the basis of a mixed heuristic visibility/encumbrance, the possible flow of people from the examined place (allowing the identification of possible "hot points") and the prevision of the reaction of the crowd to emergency events. As a consequence, the tool allows evaluating the optimal position of rescue means and personnel, of mobile obstacles and escaping routes.

In particular, our application simulates the reaction of crowds in reply to the following stimuli (which can be combined and overlapped):

- request of generic evacuation (non-localized emergencies, as earthquakes or floods)
- onset of localized emergencies with an unpredictable and persistent course (e.g. sparks due to electric short-circuits)
- onset of localized emergencies with a predictable and persistent course (e.g. fire)
- onset of localized emergencies with an unpredictable and non persistent course (e.g. explosions)

The use of the application is subdivided in three stages:

a) scene preparation, where the initialization of all possible parameters takes place. In this stage it is necessary to describe the disposition in the scenario of means and obstacles, the description and the approximated placing of crowds, the layout of the emergency generators and their characteristics (place, intensity, visibility, persistency), and the temporal sequence of the events to be simulated;
b) simulation of the crowds flow generated by the specified sequence of events;
c) visualization of the simulation process by means of interactive 3D graphics. This stage makes use of the XVR technology for the real-time rendering of interactive virtual environments (Carrozzino, 2005) and of the Virtual Crowds module (Tecchia, 2002) for the image-based rendering of the crowd.

Although the second and the third stage are logically distinct, they take place at the same time as the simulation occurs in real-time. This is needed not only in order to make efficiently use of interactive 3D graphics, but also to allow the user to activate “special” emergencies to be inserted during the course of the planned events. The simulated temporal horizon is in the range of some minutes and the maximum population allowed is 10,000 units.

The simulation exploits the subdivision of the environment in 2D micro-cells, sized about 25 x 25 cm. These cells, placed in a regular grid, may extend up to 1024x1024 units, which represent the maximum limit of this scenario spatial extension. In the visualization stage a 3D reconstruction of the real scene is presented, populated in real-time by a virtual crowd. A necessary simplification is that, in each time slice, a micro-cell may be occupied by at most one Virtual Crowd Unit (VCU). The behaviour of each single VCU is real-time evaluated depending on various factors: the presence of an emergency, the localization (if any) of the emergency, the position of the individual in the scenario, the occupancy of his field of view, the visibility of one of more outflow points, the reachability of these points etc. The real-time evolution of the behaviour of such a great number of independent units is made possible by the construction of the 2D grid associated to the 3D model representing the scenario. In fact, the presence of this grid allows to associate to each micro-cell a number of properties – many of which can be pre-calculated in the first stage, preceding the real-time visualization stage – which simplify the entity of the calculations to be performed at run-time. Therefore this grid constitutes a layer supporting the decisional process assisting the movement strategy of each unit present in the scenario. Many of the cells properties can be coded as colour, so as to allow a quick and effective accessibility, thanks to the presence in the application of dedicated functionalities of 2D image processing. The grid may therefore be coded as overlapped layers represented by 2D coloured images. It is worthy to notice that these images represent solely a support to the algorithm evaluating the crowd behaviour, therefore they do not appear in the final visualization and are used only in the real-time calculation stage.

## 5. *The behavioral model*

In the initialization stage, in addition to the 3D scenario definition, some additional parameters may be specified like the "panic proneness", to set-up an estimation of the probability of panicking for the crowd as a whole and for each single VCU. This factor will be combined, in the real-time stage, with other factors such as the proximity to the emergency zones, the number of surrounding VCUs etc. Before an emergency occurs, each VCU moves along a pseudo-random path, with a variable speed, avoiding collisions with the scenario and with other VCUs. This behaviour may be modified according to specific exigencies (e.g. when crowds constitute an audience, they may keep still or idle). Whenever an emergency occurs, the VCU behaviour may be altered in an amount of time depending on the emergency type. In fact, each emergency is marked by some peculiar factors (as its location, a propagation radius and a propagation time), which define an influence zone, growing in time, that affects the included VCUs behaviour.

When the emergency starts, in each time slice a VCU moves along a direction which is chosen in a discrete range of 64. Directions leading, in the next step, to a collision with the scenario or with other VCUs are greatly discouraged (collision avoidance). Therefore for the i-th VCU, depending on its current position $p_i$, each direction $d_{ij}$ has a cost which can be represented by a function:

$$Cost\ (p_i, d_{ij}) = f\ (ED, ES, VY, NP, IN, OB, AR)$$

where:

*ED* : Exit Distance, which is the distance from $p_i$ to an outflow point in the direction $d_{ij}$ (if no outflow exists in that direction, this parameter is maximized);

*ES* : Exit Size, which represents an estimation of how wide appears the outflow point (if any) along $d_{ij}$ (if no outflow exists in that direction, this parameter is maximized);

*VY* : Visibility, which depends on whether an outflow point is visible along $d_{ij}$ (scenario elements must not occlude the outflow point);

*NP* : Number of People, which is the number of other VCUs in a specified zone centred along $d_{ij}$;

*IN* : Inertia: depending on the VCU speed, it makes easier to choose directions closer to $d_{ij}$;

*OB* : Obstacles, represents an estimation of how free is the path along $d_{ij}$;

*AR* : Around direction, represents the average direction of the VCUs surrounding the current VCU, thus an estimation of the “flow” direction around it.

This parameters may be pseudo-randomly perturbated if the i-th VCU is in panic, event which depends on the panic proneness of the i-th VCU and on the panic status of the VCUs surrounding it. Whenever a VCU trespasses an outflow point, it is considered safe and it is not considered anymore for the purpose of the simulation. The simulation ends when all the VCUs are safe (we do not consider the possibility of losing units in the current stage of development).

The simulation provides two types of resulting data: *dynamic* data, represented by the simulation flow itself, which can be visualized from a set of fixed points or by means of a freely movable virtual camera, and *static* data, represented by a series of maps constituting different layers of information, such as the scenario map, the emergency location map and a density map representing the occupation of micro-cells during the course of the simulation. This layers provide at a quick glance information about the most walked paths and therefore may help in taking decisions about the placement of barriers to channel the crowds routes, or the setup of emergencies exits etc.

In our case this data can constitute a valid aid to individuate alternative paths that emergency operators can follow to rescue cultural assets, allowing to choose the best compromise between the need of not hampering escaping people and the necessity of acting with a fast and well planned response.

## 6. *Virtual Crowds and Cultural Heritage*

Starting from the results obtained in Piazza Napoleone in Lucca, the same application has been utilized in the case-study of a cultural property: Anagni's Cathedral, near Rome (Italy). The Cathedral was chosen due to its conformation: the church is surrounded by some annexes, as the lapidary museum, the cloister and the treasure museum in the upper floor. Thus it represents a complex case-study of interaction between architecture and people, both believers and normal tourists. A simplified 3D Model of the Cathedral was built for visualization purposes (Fig. 2a).

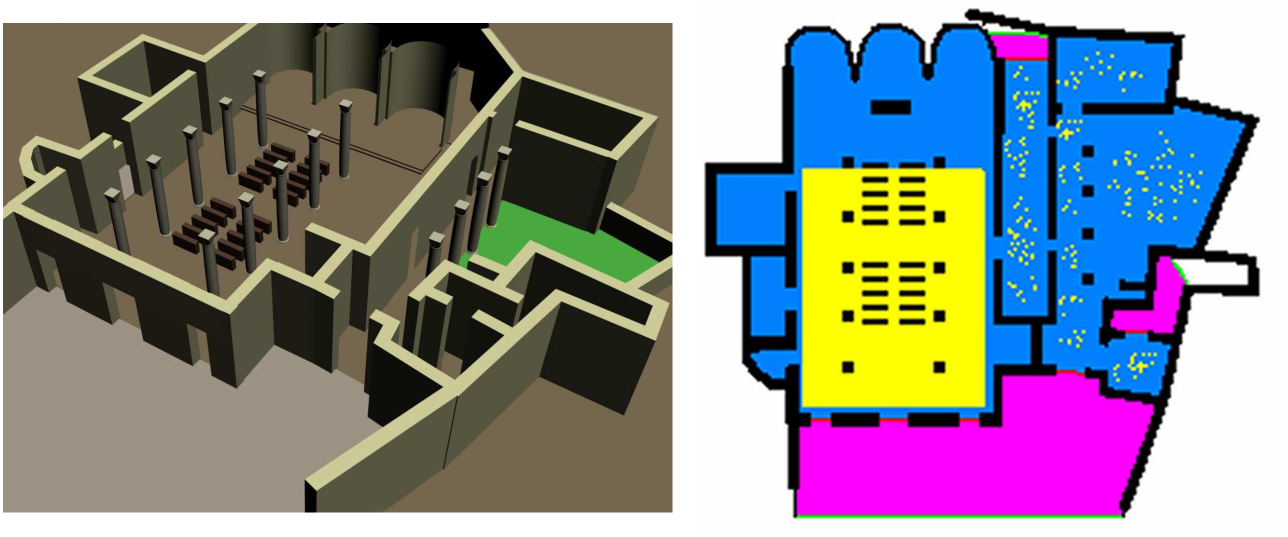


**Fig. 2:** Simplified 3D Model of the Cathedral (a) and related Scenario Map (b)

In this instance we do not deal with an open space; rather, we have a building which, differently from a square, is a covered area completely surrounded by obstacles (building's walls) and characterized by fewer opportunities of way out (building's exits); another difference is the presence of a lower number of people (about 500 VCUs).

The first consideration to be done is the distinction between localized and generic events. Indeed, the individuation of the type of incident is necessary in order to built a realistic scenario.  In the first case a focal point, representing the exact place were the emergency starts, is identified. Examples are an explosion caused by a bomb, a short circuit or a fire. In these occasions, the evacuation is firstly addressed to take people and objects away from the focal point, then to the possible paths inside the building, utilizing the emergency exits located far from the risk. If a generic event as an earthquake or a flood occurs, on the contrary, it is not possible to individuate a focal point; all the building must be considered in danger at the same moment, and the evacuation is aimed to take people and objects away from the building.

In our experiment we tested the application in the case of a generic emergency. Starting from an aerial view of the model, a 2D scenario map (Fig. 2b) was derived where every pixel is coloured according to a specific meaning:

- blue: a micro-cell where VCUs can walk, but not suitable as an initial position
- yellow: a micro-cell where VCUs can walk and suitable as an initial position
- black: a non-crossable obstacle
- red: an exit (pixels are placed along a line)
- green: a safe position (pixels are placed along a line)
- purple: a way-out zone (always delimited by a red and a green line)

**Fig. 3:** Initial distribution of VCUs

At the beginning of the simulation (Fig.3a) VCUs are randomly distributed on micro-cells corresponding to yellow pixels of the map (Fig.3b); when the emergency starts, they are free to move according to the behavioural algorithm above specified, avoiding each other and trying to reach possible exits (Fig. 4a).

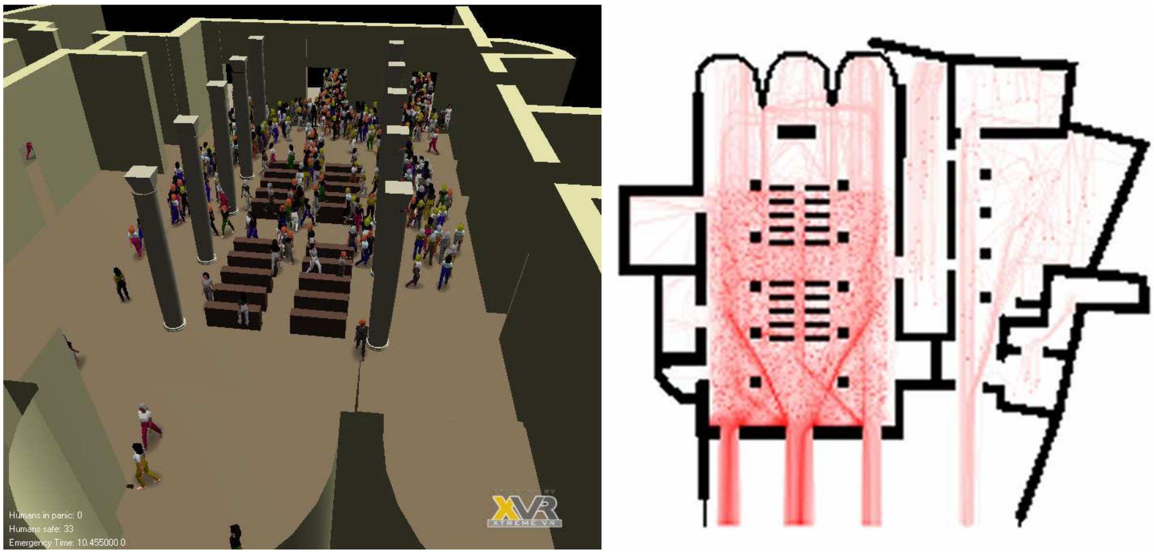


**Fig. 4:** Simulation of Crowd Dynamics inside the Cathedral (a) and Density Map (b)

Based on the movement of crowds, density maps are obtained in order to find the "crucial points", which are the points were crowd spontaneously verge on (red points). A density map obtained as a result of ten different simulations is shown in figure 4b .

Dealing with cultural properties, density maps are used not only for the individuation of evacuation paths; starting from the paths outlined to evacuate people, alternative paths, addressed to cultural properties operators, are consequently defined in order to save also cultural objects. Thus, evacuation's priority of objects and addressed paths are individuated taking into account on one side the object's artistic or symbolic value and on the other side the crowd dynamics

## 7. *Results and Future Work*

The work results highlight the relevance, among the others, of the parameter "visibility", which strongly influences behaviours and actions of the crowd flow. Since we suppose people not having knowledge of the topology of the place, they easily go towards the visible exits, even if they are placed to greater distance. Therefore the use of specific and recognizable signs may be of crucial importance in order to suggest the best ways for outflow. A good evacuation plan should include an accurate study of emergency signs and their strategic location.

For instance, in this case-study the exit behind the cathedral was not considered by the virtual crowd flow because it is not immediately visible; therefore, we propose to consider this passage suitable for cultural operators, allowing them to enter inside the building and to save cultural properties by protecting or bringing objects out (Figure 5).

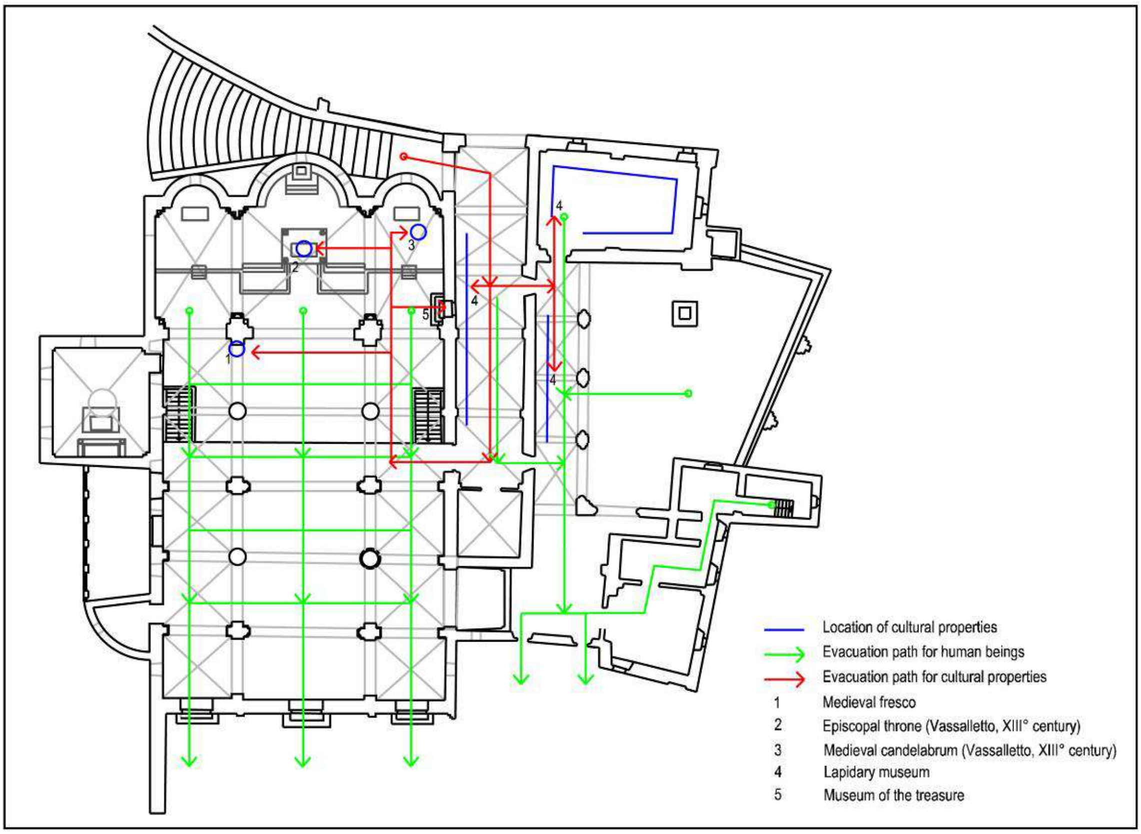


**Fig. 5:** Possible evacuation plan of the Cathedral

A possible improvement of the simulation could consist in the individuation of "intermediate" objectives (i.e. visible passages), which VCUs may try to achieve when more important objectives (i.e. main exits) are not immediately or easily reachable. Such a strategy may allow to bring VCUs situated far from exits, or surrounded by large amounts of other VCUs compromising their visibility, in positions where other secondary exits, previously not visible, become accessible.

Currently we are focusing on setting up procedures for the experimental validation of the implemented behavioural model. An interesting descriptive solution is proposed in (Sharma, 2005), where data coming from studies of real humans (traced by means of RFID detection) is compared with the simulated behaviours. So far authors claim to have obtained good results with small-scale crowds and places, therefore testing this procedure in wide-scale scenarios may be an interesting step forward. At the same time, a parallel task regards the identification of possible additional parameters to be inserted in the simulation model, although we have to constantly keep into account the computational weight (and therefore to individuate possible simplifications) in order to comply with real-time requirements. Also in this case the comparison with real data may help not only in validating the current model but also in setting up a more detailed and realistic model.

The main drawback in the validation by real human data is the objective difficulty to gather this kind of data, especially in case of large crowds. Possible alternative solutions might involve human-operated virtual crowds. An interesting opportunity is offered by online virtual worlds (such as Second Life[3], probably the most known and widespread multi-user virtual world although currently declining) or by many Massively Multiplayer Online Games[4]. However, in this case there are some serious issues to take into account:

- moving in a virtual world like might require using mouse, keyboard, or joystick, which may be not the most comfortable interfaces to drive avatar movements. This may result in clumsy movements depending on the interface, rather than on the scenario elements, dangers and obstacles. However, this issue may be addressed by targeting skilled users experienced with these interfaces.
- some behavioural rules, which users should strictly observe, must be set, starting from the most elementary ones (avoiding non-natural, yet allowed in the virtual world, behaviours such as flying) to more peculiar ones (people should behave as if they actually were in an emergency situation, trying to escape the place as soon as they can). Naturally, the resulting behaviour will barely approximate the corresponding real behaviour (panic and danger feeling are impossible to replicate), however some kind of "excitement" soliciting an aimed, but somehow altered, behaviour, could be possible performing the experiment in the context of a competition ensuring a reward (in game terms) for the best performers.

Besides its capabilities as support for planning, a real-time system like the one proposed may be proficiently used also for training purposes. In fact the emergency operators could be trained in a immersive environment (such as a CAVE-like system, Fig. 6) in order to experiment in first person the feasibility of covering the planned paths while feeling

---

[3] hhtp://www.secondlife.com
[4] http://en.wikipedia.org/wiki/ Massively_multiplayer_online_game

surrounded from escaping crowds in a scenario faithfully reproducing the desired real one, with strict time constraints.

**Fig. 6:** Immersive Rendering of Crowds in the X-Cave at PERCRO laboratory

A higher level of realism and, consequently, a better implementation of this training procedure may be achieved by using an Augmented Reality system, where the operator is situated in the real place and has to physically perform his task while seeing, co-located in space and time, visual stimuli on his HMD representing the flow of virtual crowds populating the real scenario. Although more demanding in terms of structures and logistics, exercitations of this type may actually result very effective for emergency planning.

## REFERENCES

ALEXANDER, D. (2002) “Principles of emergency planning and management”, pp. 238-239, Oxford University Press

ZARBOUTIS N., MARMARAS N. (2005) “Investigating Crowd Behaviour during Emergency Evacuations Using Agent-Based Modelling. In EAM 2005 proceedings, Oct. 17th-19th, Athens, Greece.

LINDEL M., PERRY R. W. (1991), Understanding evacuation behaviour, IJMED, August 1991, Vol. 9, No 2, pp. 133-136.

LOSCOS C., MARCHAL D., MEYER A. (2001), Intuitive Crowd Behaviour in Dense Urban Environments using Local Laws

ULICNY B., THALMANN D. (2001) “Crowd simulation for reactive virtual environments and VR training systems”, in Proc. Eurographics Workshop on Animation and Simulation, Springer, Heidelberg

STREETER, C. L. (1991), Redundancy in social systems: implications for warning and evacuation planning, in International Journal of Mass Emergencies and Disasters. August 1991, Vol 9, No. 2, pp. 173-174

HANNA J. A. (1994), Emergency Preparedness Guidelines For Mass, Crowd-Intensive Events, Minister of Public Works and Government Services, Government of Canada.

PODANY J. (1991), Developing and Practicing an Emergency and Disaster Response Plan, in 1997 Kobe/Tokyo international symposium on risk preparedness for cultural properties. Kobe, 1997, pp. 347-349.

NELSON C. L. (1991), Protecting the past from natural disasters, National Trust for Historic Preservation, p. 67, John Wiley & Sons

ALEXANDER, D. (2002) “Disasters tend to be repetitive events, they form a cycle that can be divided into phases of mitigation, preparedness, response, recovery” in “Principles of emergency planning and management”, pp. 4-7, Oxford University Press, p. 5

LINDELL M. K., PERRY R. W. (1991), Understanding evacuation behaviour: an editorial introduction, in International Journal of Mass Emergency and Disasters, August 1991, Vol. 9, No. 2, p 133

HELBING, D., FARKAS, I. J., MOLNAR, P., AND VICSEK, T., (2001), Simulation of pedestrian crowds in normal and evacuation situations, In Pedestrian and Evacuation Dynamics, edited by M. Schreckenberg and S. D. Sharma (Berlin: Springer-Verlag), pp. 21-58.

XIAOPING Z., TINGKUAN Z., MENGTING L. (2009), Modeling crowd evacuation of a building based on seven methodological approaches, Building and Environment 44 (3) 437–445

CARROZZINO M., TECCHIA F., BACINELLI S., BERGAMASCO M., (2005) Lowering the Development Time of Multimodal Interactive Application: The Real-life Experience of the XVR Project, Proceedings of ACE 2005, Valencia, Spain

TECCHIA F., LOSCOS C., CHRYSANTHOU Y. (2002), Image-based crowd rendering, IEEE computer graphics and applications, March/April 2002, p. 36-43.

SHARMA, S., GIFFORD, S. (2005) Using RFID to evaluate evacuation behavior models Proceedings of the North American Fuzzy Information Processing Society.