ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume IV-4, 2018
ISPRS TC IV Mid-term Symposium “3D Spatial Information Science – The Engine of Change”, 1–5 October 2018, Delft, The Netherlands

3D GEOSPATIAL INDOOR NAVIGATION FOR DISASTER RISK REDUCTION AND RESPONSE IN URBAN ENVIRONMENT

Tarun Ghawana[1] Mitko Aleksandrov[2], Sisi Zlatanova[2]

[1]Integrated Spatial Analytics Consultants, India. E-mail address:tarungh@gmail.com;
[2]UNSW Built Environment, Red centre Building, West wing, NSW 2052, Sydney, Australia. E-mail address: {mitko.aleksandrov@unsw.edu.au; s.zlatanova@unsw.edu.au}

Commission IV, WG IV/5

KEY WORDS: 3D, Disaster Management, Indoor, Models, Navigation, Evacuation

ABSTRACT:

Disaster management for urban environments with complex structures requires 3D extensions of indoor applications to support better risk reduction and response strategies. The paper highlights the need for assessment and explores the role of 3D geospatial information and modeling regarding the indoor structure and navigational routes which can be utilized as disaster risk reduction and response strategy. The reviewed models or methods are analysed testing parameters in the context of indoor risk and disaster management. These parameters are level of detail, connection to outdoor, spatial model and network, handling constraints. 3D reconstruction of indoors requires the structural data to be collected in a feasible manner with sufficient details. Defining the indoor space along with obstacles is important for navigation. Readily available technologies embedded in smartphones allow development of mobile applications for data collection, visualization and navigation enabling access by masses at low cost. The paper concludes with recommendations for 3D modeling, navigation and visualization of data using readily available smartphone technologies, drones as well as advanced robotics for Disaster Management.

1. INTRODUCTION

Modern urban environments are becoming increasingly complex infrastructure development areas with a dense population in high-rise residential, commercial and office buildings (KPMG, 2012). During disaster events such as earthquakes, fires or terrorist attacks rapid building access and evacuation is required demanding pre-planning of access and escape routes (Ronchi, 2015). Proper information about building structure and materials, possible escape routes, potential obstacles (such as furniture and dynamic blockades) as well as indoor-outdoor connection in different disaster scenarios are essential to devise a good response strategy. Spatial information with non-spatial attributes about these features in 3D format can be used to generate scenarios which can help to optimize the resources at hand for saving lives and valuables. The paper assesses the need for 3D geoinformation and explores approaches for 3D indoor modeling, navigation, evacuation and visualization which can be utilized in disaster risk reduction (DRR) and response strategy for a high-rise and complex building structure. For this purpose, several papers have been reviewed.

Disaster events due to their very nature often require a swift response with a focus on saving human lives and the infrastructure. Proper pre-planning in complex infrastructures considering predefined escape plans, escape routes and response of occupants is required in rapid evacuations due to big fires and earthquake incidents (Ronchi et al., 2013)

Similarly, responders need to have an evacuation strategy at hand in case of the fire incident, also a strategy to access the building and reach the source of fire for extinguishing based on indoor floor plans of the structure (OSHA, 2001). This has to be done primarily for drawing a response route for the responders. In addition, they need to assess the approximate time for reaching the desired place in the building based on distance, the location of obstacles, type of structure, and other materials expected inside. Locational information of these obstacles, escape routes, storage points, etc. is required in multi-floor large buildings in addition to the floor connecting stairs, inside and outside connecting corridors or lobbies. This locational information in traditional 2D mode is less effective compared to 3D spatial information for understanding the indoor structural formation and navigating optimally (Gangraker et al., 2015). Figure 1 illustrates an imaginary use of 3D indoor information in an emergency situation.

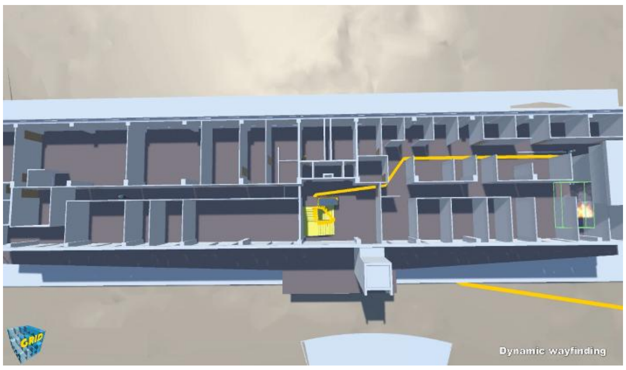

Figure 1: 3D simulation of dynamic wayfinding in case of fire on a staircase, UNSW, Sydney

Obtaining 3D indoor spatial information has been researched upon in various publications, and many 3D approaches have been devised. However, the 3D models need additional enrichments and links to many other data sets to be able to support disaster risk reduction and response effectively.

This paper is organized further as follows: section two discusses requirements of 3D information for support disaster risk reduction and response, section three reviews 3D reconstruction approaches, section four is dedicated to models and data structures, section five briefly discusses methods for path finding, section six elaborates on evacuation simulation, section seven

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
https://doi.org/10.5194/isprs-annals-IV-4-49-2018

touches upon seamless indoor/outdoor navigation and section eight is dedicated to visualisation approaches. The last section concludes the study and suggests directions for research and developments.

2. REQUIREMENTS OF 3D INDOOR INFORMATION FOR DISASTER RISK REDUCTION AND RESPONSE

Disaster risk reduction and response requires devising mitigation strategies to reduce the impact of any emergency event. It requires planning with proper information. Using spatial information provides the capability to capture the emergency situation better, consider various parameters and create a better common operational picture (Diehl et al., 2005). Traditionally spatial information for disaster planning has been available in 2D format on paper or even in digital images or graphics with limited interactive capability. With the advent of information technology in general and advancements in spatial science-based GIS and Remote Sensing technologies, 3D information is getting generated on the much wider scale. It is primarily used for visualization purpose and as a virtual reality training tool (Berlo et al., 2005). However, with time it is emerging as an analytical instrument with more realistic views and simulations for different applications such as plume modelling, forest fire simulation or landslides (Wang et al., 2017; Kemeç et al., 2010).

With rapid urbanization, infrastructure density has increased resulting in the development of complex three-dimensional structures on a large scale which have grown in the shape of underground networks or basements as well as multi-floor high rise buildings.

2.1 Requirements

1. 3D reconstruction of indoor spaces should be done in a quick and feasible manner trajectory (Holenstein et al., 2011; Staats et al., 2017).
2. The reconstruction approaches should be able to collect information about obstacles.
3. The 3D models should be semantically enriched containing information about properties of building components and spaces of importance for DRR (Diakité et al., 2016 a).
4. Information about accurate connectivity and accessibility of spaces should be recorded in the models, emphasizing potential openings in case of disaster.
5. The information should be organized in a way that allows flexible derivation of navigation networks, which enables user-tailored navigation, considering their profile as well as tasks
6. The models should support the development of applications on different platforms.
7. The navigation should consider different environmental conditions that might occur during emergencies, e.g. smoke, lack of electricity, water, not using elevators
8. Constraints to wayfinding need to be dealt for route planning (Stoffel et al., 2007)..
9. The developed interfaces should be simple and expressive.
10. The developed applications should have a self-contained variant, being able to work with or without internet access.

Therefore, the importance of 3D indoor geospatial information is increasing for an efficient and quick response. This justifies the need to develop methods which can provide reliable, accurate, context wise semantics-based 3D indoor data for reconstruction and navigation purposes on a mass scale.

The reviewed approaches and models or methods are analyzed in terms of several parameters in the context of indoor risk and disaster management. These parameters are implementation, connection to outdoor, spatial model and network, constraints handling. This will help to classify the models in different categories.

3. 3D DATA COLLECTION AND RECONSTRUCTION

Terrestrial laser scanners and handheld devices have proven to be most suitable for data capturing of indoor spaces. Mobile Laser Scanner (MLS) devices are more efficient than static terrestrial scanners since they can provide a continuous scan of the environment following a trajectory (Holenstein et al., 2011; Staats et al., 2017). Sensors such as Kinect V2 from Microsoft are popular among the RGB-D cameras (Figure 2). These sensors provide low-cost and accurate depth images after proper calibration and thus can be used for 3D reconstruction (Jiao et al., 2017). Another approach aiming at quick collection of data is the use of micro unmanned aerial vehicles (UAVs) for 3D mapping of the facility have been suggested using 3D axis parallel box (APB) approach which in plural sense include maps closed to basic set operations of union, intersection and set difference, etc. (Leth et al., 2017). Another example is Google-Tango Development Kit, which enables indoor reconstruction combining different sensors (Gülch, 2016).

For the purpose of quick processing of point clouds, a common method to structure and segment a point cloud is through an octree data structure. One of the advantages of an octree is efficient structuring of space, in which case a large empty space can be represented by a large node high in the octree (Rodenberg et al., 2016).

Reconstruction of semantic and geometric components include volume shifting and loop closure, the coarse-to-fine iterative closest point (ICP) algorithm, the SIFT odometry, inertial measurement unit (IMU) odometry combined to robustly and precisely estimate pose and least square adjustment algorithm (Huai et al., 2015, Jamali et al., 2015). Contextual relationships as well as local features based planar patches can be input for the classification algorithms (Xiong et al., 2010).

An 3D environment can be enriched using textures which can be artificial or image based. Stock objects from 3D warehouses (e.g., Google 3D Warehouse) can also be used for this purpose. Further enhancement can be done by importing such models into 3D gaming engines for instance Unity3D (Gangraker et al., 2015). Another way is to use a vocal interface with contextual information about the surrounding environment (Ran et al., 2004). In case of incomplete knowledge of the space, actions can be used to generate further observations and thus derived knowledge to achieve the goal (Raubal, 1999).

Another example could be the grammar-based approach for the robust automatic reconstruction of 3D interiors from raw point clouds. This approach enables building modelling with rooms access through hallways on horizontal, continuous floors. Seamless transition from LOD3 to LOD4 building models is possible by embedding such grammar in an iterative automatic learning process. After the initial grammar, higher-level grammar can be applied to predict realistic geometries to building parts where only sparse observation data are available (Becker et al., 2015). Too much reliability on empirical analysis in case of absence of large datasets needs to be tackled with human interpretation of results based on experience and expert judgement.

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To be able to collect information about potential obstacles in indoor environment from existing plans different approaches have been explored, which can allow the automatic prediction and generation of building floor plans serving as the basis of building a 3D indoor model using architectural regularities and probability distributions for doors location prediction (Dehbi et al., 2017).

Point clouds can also be utilized to detect potential obstacles (Vilariño et al., 2016). Such models could be developed as interactive and context-sensitive by utilizing the sensor on the mobile devices which include built-in accelerometer, compass and camera capabilities (Low et al., 2015).

All such methods differ in one way or another. The, laser scanner sensors use separate technologies and designs for 3D model generation along with different prices, sizes, quality, measurement capabilities and additional requirements of usage. Besides accuracy and suitability for emergencies, very often access to devices and transporting them to the place to be modeled are points of importance (Sirmacek et al., 2016).

This section highlights the importance of 3D data collection and reconstruction aspects which could be highly useful for DRR and disaster response activities. Importance of efficient and reliable data collection with quick processing of data has been highlighted. Enriching the data with semantics attributes, geometric attributes and textures can generate more realistic environment in 3D for DRR and response planning. Detection and prediction of potential obstacles could enhance these disaster management efforts.

4. 3D DATA STRUCTURING

With the passage of time, 3D models have become more realistic and have multiple applications especially in a city environment (Biljecki et al., 2015). There are many ways to manage indoor 3D models. Very often to represent one, there are three main ways such as cloud points, meshes or BIM. Although the first two maintain only geometry and no semantics is possible to store, using BIM metadata of the objects can be integrated as well. A file format enabling rich semantics descriptions of 3D data exchange is IFC and CityGML LOD 4 having a deeper focus on modeling indoor 3D environment.

When it comes to indoor 3D building navigation, various conceptual models have been proposed (Lamarche et al., 2004; Li et al., 2008; Yuan et al., 2010; Goetz et al., 2011; Liu et al., 2011). For the purpose of navigation, Geometric Network Model (GNM) is one of commonly utilized methods to represent a navigable network, which consists of nodes representing spaces where objects can be located and edges connecting the nodes indicating the connectivity. The concept of duality has been widely used in the literature and has been adopted by the OGC standards IndoorGML (Li et al., 2010; Kang et al., 2017). IndoorGML can be linked to popular semantic and constraint models as CityGML LOD 4 and IFC model with geometrically and topologically valid objects (Diakité et al., 2016 b; Brown et al., 2013).

Based on dual model concepts, primal model and other cells could be connected (Jamali et al., 2016). Thus, an automated 3D modeling of indoor navigation network is proposed (Jamali et al., 2017). Several space models can be connected in a Multilayered Space-Event Model (MLSEM), which can provide a flexible framework supporting all indoor navigation tasks (Becker et al., 2009). Applying MLSEM concept, space subdivisions based on topographic, sensor access and so forth criteria can be linked and analyzed together (Nagel et al., 2011).

Other examples of spatial models for navigation can be data model based on the BISDM (Building Interior Space Data Model) of ESRI where feature classes are divided into three groups: Building Structure; Infrastructure and Equipment in the Building; Transportation Network in the Building (Gotlib et al., 2013). Basic building units, for instance, rooms or parcels can be considered as cells defined by attributes. A multi-floor adjacency cell and semantic-based index (MACSI) approach integrates the indoor cellular space with the semantic space optimizes the adjacency distances between three dimensionally connected cells (e.g. elevators and stairs) based on the caloric cost (Lin et al., 2016). Another space model is the "space in a space" model, where spaces may be related while other spaces are disjoint (Schabus et al., 2015).

BIM is a relatively new concept becoming a popular standard in the construction industry, such as Industry Foundation Classes (IFC). Such standards enable describing semantic and geometric properties of building components along with their spatial relationships. Using semantically rich and furnished IFC models, 3D spaces free of obstacles can be extracted (Diakité et al., 2016 a). There is various information that can be extracted from semantically rich BIM for DRR. Thus, information of emergency utilities, architectural components and hazardous materials locations can be extracted (Tashakkori et al., 2016). But 3D semantically rich models as BIM can be very complex and difficult to maintain and update. They get easily outdated, and therefore they are often neglected even if they exist.

Indoor environment can be divided into subspaces to represent better the location of the user. Another large group of papers concentrates on space subdivision. One example of them is a subdivision into convex subshapes called "e-spaces" which can be connected, if visible mutually, by the algorithm for wayfinding (Vaiene et al., 2016).

The models differ from each other in the sense that some of them are simple, but generic and easy to implement, others are semantically rich and thus allowing for more accurate navigation networks but are rather heavy and tricky to implement on mobile devices. Cloud point based models can be used to simply generate physical space models and thus could be relatively generic in defining the spaces likes LOD1 and LOD2 of CityGML. In case of dual-space or multi-space models, defining the space could be physical, topological or legal with semantics, thus making the data structure of such models more complex. Defining spatial relationships between spaces and navigable networks could make models such as BISDM more challenging to implement.

5. 3D INDOOR NAVIGATION

Next step after defining the 3D model is indoor wayfinding or navigation Figure 2. In case of indoor navigation, the path of a person is not limited the way it is for a car in case of outdoor navigation (Gotlib et al., 2013). In case of emergencies, two types of navigation can be considered: 1) from outside to indoor for rescuers and responders and 2) from indoor to outdoor to aid people in need. Depending on the type of user the applications differ.

Important building information within the spatial context of the rescuer can be provided on a mobile device for rescuers (Rueppel et al., 2009). In case of response process initiated, indoor and outdoor drones can perform monitoring both inside and outside the building, sending all visual data to the server (Maravall et al., 2017). This visual data can be utilized by rescuers. Indoor navigation for evacuees requires a guidance system which could be based on navigation algorithm devised using information on hazardous areas, emergency spreading, congestion areas (Weeraddana et al., 2013).

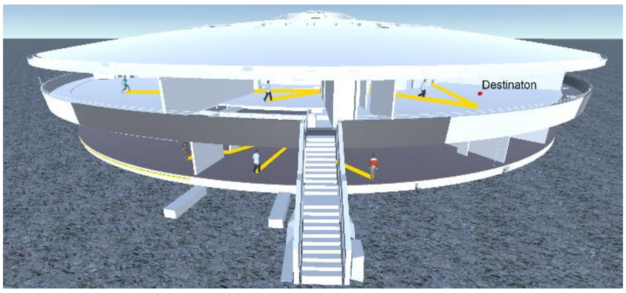

Figure 2: Indoor wayfinding to a specific destination, Round House, UNSW, Sydney

Another specific application of indoor navigation research is for routing purposes to fulfil the transportation necessities of each production asset (Scholz et al., 2017). Similarly, a user can be a normal person with no problems with eyesight while another user could be a visually impaired person or a person in an environment with bad visibility (e.g. smoke). Thus, indoor navigation aid has to be developed accordingly taking care of the specific requirements of a user (Ran et al., 2004).

Physical 3D environment that a person requires to move through should also be modelled defining the accessibility for different people. For instance, an accessibility map for people with disabilities using wheelchairs and first responders caring specialized equipment can vary compared to ordinary people. Hence, in order to calculate the accessibility map aspects related to max slope that a person can climb along with step height and person's radius and height should be taken into account (Barrera et al., 2015).

Another aspect which directly impacts navigation of people and wayfinding in indoor environments are different navigation areas that a person can use such as open spaces, corridors, doors, stairs, elevators and escalators (Bukowski et al., 2016). Apart from that other people having the same trajectory can influence the navigation process (Braun et al., 2003). Therefore, considering the impact of the number of people residing a building during a different period of a day should be considered for path calculation (Tashakkori et al., 2016).

Thus, two navigation types are identified: outdoor/indoor navigation for first responders and indoor/outdoor navigation for evacuees. Regarding first responders, real-time information about the current situation and the best route should be provided. When it comes to evacuees, aspects such as people abilities and their performance using different egress components should be taken into account to provide the best navigation for them.

6. REQUIREMENTS EVACUATION

Evacuation is one of the most critical activities during emergencies. People have to be lead outside the building to a specific safe place in an appropriate period. Usually, these estimations are made in advance during the risk preparedness phase and are validated with the help of simulation models.

One of the approaches for simulating an evacuation is Multiple Ant Colony Optimization (MACO) algorithm coupled with heuristic information, two-colony rules and local search for generating optimal indoor room spatial patterns (Yang et al., 2017). In case of a disaster event, Ant Colony Based algorithm can find the required number of first responders and their potential individual routes to search points of interest in a building which will minimize the overall time spent by all rescuers inside the disaster area (Tashakkori et al., 2016). Based on a swarm algorithm, swarm creatures can search for the requested target and, once found, return to the user whilst creating a path (Yoon et al., 2006).

In order to track evacuees' movements data from RFID devices and smartphones can be used (Ortakci et al., 2015). Also, surveillance videos can be processed to detect their movements (Zhou et al., 2016). Another approach suggests using the concept of decentralized evacuation targeting single evacuees in a dynamically changing environment with risk-aware guidance on their smartphones. Information depositories, collecting the knowledge acquired by the smartphones of evacuees passing by, at strategic locations convey it to other passing-by evacuees (Zhao et al., 2017). 3D localization approaches can be based on the use of Bluetooth (BT) radio technology and implemented using Java and J2ME (Cruz et al., 2011).

An important aspect of evacuation is guidance. Landmarks fetched in the memory of evacuees or responders can help them to prepare a mental map of the optimal route for escape or evacuation. Algorithms used can calculate path linking the minimal amount of actions to the landmarks (Vaiene et al., 2016). An optimization technique considering time-space-based risk is proposed taking into account the spatial location of evacuees within a building to minimize the risk (Han et al., 2007). One interesting approach used is of navigation graphs with weights, done with affordances based on ontology (Scholz et al., 2017).

Visibility and generating route descriptions are some aspects need to be accounted for implementation of the constraint models (Stoffel et al., 2007). 3D engines have some capabilities to handle collision avoidance during route planning. For example, the physics component of the Unity Engine (Gangraker et al., 2015). Mosaics can be used to map local areas to ease user navigation through streets and hallways, by providing a wider field of view (FOV) and the inclusion of more decisive features. Besides, audio support, visual support can be considered as signage, visual-text, and visual-icons for augmenting environments (Molina et al., 2012).

3D information is essential to determine required safe egress time (RSET) performing evacuation simulations to understand evacuees' performance as well as to accurately calculate available safe egress time (ASET) carrying out fire simulations (Bukowski et al., 2016).

Several important aspects have been identified in this section presenting the components that should be considered for effective evacuation and DRR. Thus, different algorithms based on ant colony and swarm optimization can be utilized to find the best option among the available set of solutions integrating various aspects such as risk, dangerous locations and people preferences. Localization and dissemination of information to evacuees is another important aspect which needs careful investigation for DRR. Different methods such as audio support, the use of text

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and arrow based signage can be utilized to reduce the risk during an evacuation. 3D information can be also used to determine RSET and ASET times to provide safe evacuation for evacuees though a building.

7. SEAMLESS INDOOR/OUTDOOR

With the increased urbanization, there is a rise in development of complex buildings where connection to outdoor becomes important because of associated rights of access and usage through the connecting pathway. Integration of concepts of indoor and outdoor should be performed by studying its impact on route planning (Philippe et al., 2012).

In many cases indoor location is more appropriate to be given as a relative location, such as ‘next to’, ‘at from of’, or ‘close to’, and approach which is not used for outdoor navigation (Sithole et al., 2016). Indoor Navigation models such as IndoorLocationGML can support establishing such locations and linking them to outdoor notations for seamless indoor-outdoor expression of location (Zhu et al., 2016). Using mobile phone base station’s signal patterns could be an approach to identify the users’ location (Wang et al., 2016).

8. VISUALIZATION AND GUIDANCE

Many libraries are currently available to develop personalised applications. 3D gaming engines make readily available a number of utilities in a package form as a software development kit (SDK). Thus, various SDKs are compatible with mobile devices providing core components such as rendering engine, media engine, physics engine, scripting functionality, networking capability and even Artificial Intelligence (AI). For emergency situations, the role of renderer component is critical due to its interaction with user and allows having 2D or 3D display of the surrounding environment (Gangraker et al., 2015).

One of the promising gaming engines is Unity3D, which enables development of a Graphic User Interface (GUI) which can reflect specific needs or tasks. Also, objects that are within a visible field of view can be rendered, and thus increase the performance of a graphical processing unit (Lovreglio et al., 2018). Another suitable 3D gaming engines is 3DState (Rahman et al., 2007). Research has been conducted connecting indoor modeling process, route finding and visualization using CityEngine (Kim et al., 2015). A multi-layer system with application, web-service and database can be developed to provide services of localization, navigation and visualization (Xu et al., 2013). However, such internet-based approaches should be used with care in case of emergency response as internet connection might fail.

Navigable areas can be automatically extracted and presented over the physical 3D space enabling a person to intelligently move through an available walkable environment, which option is also available within Unity3D. Visualization of different navigable layers within a building impacting the speed of people as well as the calculation of the shortest path, using A* algorithm considering layers’ costs and even dynamic obstacles, can be undertaken at runtime (Barrera et al., 2015).

In case of emergency, instant visualization on a mobile device with proper information of static obstacles and direction could be useful for responders as well as victims. Direction presented in a visual manner can prevent the disoriented victims, blinded due to invisibility, from getting trapped even when they know the building interiors. For this purpose, Mobile applications have been developed for smartphones to provide the user with such visual support (Ortakci et al., 2014). Static obstacle positions can also be pre-defined (Mutlu et al., 2012). Indoor architecture is represented via corner based feature points obtained through a monocular camera (Celik et al., 2008). Smartphones are readily available which have a geomagnetic sensor which can be used for designing a geomagnetic positioning indoor navigation system based on Android platform (Jiaxing et al., 2017). Research topics have also explored solutions for navigation with a different perspective for evaluating the ease of wayfinding, considering 3D interactions between wayfinding behaviors and signage location, visibility, legibility, noticeability, and continuity to detect ‘disorientation spots’ such as forks (Maruyama et al., 2017). External information can be used (e.g., signage) as a wayfinding aid (Vilar et al., 2012) during emergency route planning. A digital sign system with designated patterns can be readily detected and identified with a digital camera and machine-vision system (Tjan et al., 2005). These digital signages can flash updated emergency messages for evacuees or responders.

9. DISCUSSION AND RECOMMENDATIONS

Disaster management is an integral part of planning and development of urban areas in developed countries. The similar issue face high-rise multi-story complex infrastructure environment in metro cities of fast developing economies like India and China, it is going to be an important component of infrastructure development plans. With densely populated areas having complex structures, there is always a possibility of emergency situations like fires or earthquake or flash floods, endangering human lives and infrastructure. Disaster management for urban environments with complex structures requires to focus on 3D indoor applications development as risk reduction and response strategies.

As part of DRR and response strategy, the most critical aspect for indoor applications is the generation and maintenance of 3D information. Generating three-dimensional spatial data with a reliable method on a mass scale at rapid speed is essential to widespread the awareness to use such data among planners. 3D information serves as the basis of modeling for 3D data structuring, visualization and guidance, 3D indoor construction, seamless indoor-outdoor connection and evacuation. This kind of information requires technical accessories and skills available in the form of software & hardware platforms. Our review has shown that such methods exist, but information is unstructured and can be used only for observation. 3D data collection is becoming quick and cheap, but the 3D reconstruction methods are still at experimental stage.

The study clearly shows that terrestrial and mobile scanners are mostly used to generate semantically rich 3D reconstructions. To fulfill geometric measurements and CAD models with high level semantics in the form of key structural components such as walls, floors and ceilings along with their spatial relationships, much research is needed. Standard representations such as BIM and CityGML LOD4 could be very helpful to facilitate exchange and re-use of 3D models, and they have to be maintained and up-to-date. Such accurate geometric and high level semantic information can allow planners to develop very realistic mitigation measures as part of the DRR efforts. Responders will also get very good virtual environments to train in the preparation phase or to create an accurate common operational picture during the emergency.

Information about accessibility of spaces (based on use of spaces) is of critical importance and should be further investigated

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(Alattas et al., 2017). With 3D information of indoor space, limitless benefits can be achieved such as modelling and calculation of more accurate network routes, precise identification of navigable spaces for users with different capabilities and preferences, better understanding of daily activities of residents, performing realistic RSET and ASET calculations, risk reduction of evacuees considering spatial location of dangerous locations and rapid distribution of first responders for better coverage within a building. 3D reconstruction approaches should also consider mechanical, electrical and plumbing (MEP) designs more and more as integral part of building structure. This will allow to generate better response measures and to consider alternate routes of evacuations with more knowledge of building structural intricacies.

Data structures for indoor should allow to organize and process the data to support more elaborated queries compared to outdoor. These structures should be standardized to facilitate sharing and exchange of information. Our study has shown that indoor 3D models can have many representations and management of data is performed in different ways. 3D graphics formats (without semantics) is suitable for simple cases and common navigation in regularly structured buildings. However, for more complex situations, more semantics and attributes need to be defined. In this respect many attempts have been made to integrate data from different domains, e.g. IFC and CityGML.

For the purpose of navigation, standardisation approaches to create Geometric Network Model have been gaining interest. In this respect IndoorGML can be mentioned as one promising concept, allowing to create navigation models on the basis of duality of space and indication about connectivity. This concept is further extended to link different space models, which can be organized in a Multilayered Space-Event Model (MLSEM). This provides a flexible framework supporting all indoor navigation tasks. By dividing indoor environment into subspaces and automatically deriving a network, a more refined navigation paths can be computed that considers the task of the navigated agent (user or robot).

These developments must be further intensified and specialized for DRR considering the storage space and processing power required to subdivide the space of interest and tasks to be executed. In case of response to a disaster event, the urgency of the nature of the event, develops requirement to process the data at high speeds considering the dynamics of changing the environment.

Indoor navigation is not only about defining the space models but also developing routes which should be cost effective in terms of time, distance, safety, security or physical effort. Avoiding obstacles is an integral part of it. Indoor navigation aid has to take into context the specific requirements of a user. For rescuers, mobile devices such as smartphones and drones can play an important role by providing inputs about the building structure and displaying the potential routes and obstacles while on the move. Thus, indoor accessibility and evacuation maps have to be extended, considering the physical criteria such as corridor slope or stairs to be climbed and user context such as disable victims and rescuers carrying specialized equipment, need to be developed as a part of DRR efforts.

Using technological advancements must go beyond information to be used by humans in case of disaster events. Similar to drones, the field of robotics has now advanced enough to develop robots which can perform indoor navigation tasks swiftly while avoiding obstacles in the path. Robots can take place or assist human rescuers with enhanced speed, agility, maneuverability, load carrying capacity, resistance to fire, laser and infra-red based visual. Examples of such robots have been developed by the company Boston Dynamics (Boston Dynamics, n.d.; Dailymail, 2018) which can perform such tasks and have been well demonstrated in indoor and outdoor spaces (Figure3) .

Figure 3: Boston Dynamics robot climbing stairs, while avoiding obstacles: Source: Dailymail, 2018

Any DRR and response strategy has the safe evacuation of victims trapped inside a structure as the first and foremost target to be achieved. This critical activity requires estimates to be made in advance as part of DRR efforts. Reviewed literature showed that most studied approach is Ant Colony Optimization (MACO) algorithm. Importance of mental maps defining an optimal route for escape or evacuation are mentioned in the reviewed literature. Safe evacuation is directly linked to time as a crucial factor. 3D information of indoor environment can enable accurate calculations of RSET and ASET and facilitate modeling of evacuation process. Audio & visual support as announcements, signage, visual-text, and visual-icons can be considered for augmenting environments.

Another critical issue is seamless outdoor and indoor connection, which are important for both evacuation planning and individual guidance. Current approaches of linking outdoor and outdoor networks via anchor points are trivial but insufficient for DRR. The existing outdoor networks fail to provide accurate paths appropriate for human movements. In this respect, an extension of the indoor approaches for navigation could be an option for outdoor.

Using realistic visuals and appropriate guidance on the basis of 3D rendering engines can enhance the perception and comfort of the user. Visual guidance should be combined with sound interfaces. For example, smoke, engulfing the building, or electricity failure can be a reason for reduced visibility, which will require a vocal interface with contextual information about the surrounding environment.

With readily available mobile technologies, the rapid development of mobile applications is observed, but these applications should be extended to serve emergency situations. In case of disaster scenarios, such mobile applications should allow users to plan the escape routes on their own as well as to connect with responders in a 3D visual way for further guidance.

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