BIM Support for Disaster Response

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The introduction of Building Information Modelling (BIM) to the design, construction and operation of buildings is changing the way that the building construction industry works. BIM involves the development of a full 3D virtual model of a building which not only contains the 3D information necessary to show the building as it will appear, but also contains significant additional data about each component in the building. BIM represents both physical and virtual objects in a building. This includes the rooms and spaces within and around the building. The additional data stored on each part of the building can support building maintenance operations and, more importantly from the perspective of this paper, support the generation and running of simulations of the operation of the building and behaviour of people within it under both normal and emergency scenarios.

The initial discussion is around the use of BIM to support the design of resilient buildings which references the various codes and standards that define current best practice. The remainder of the discussion uses various recent events as the basis for discussion on how BIM could have been used to support rapid recovery and rebuilding.

Key Words : *BIM, VDC, disaster management, building modeling, sensor integration*

1. INTRODUCTION

Buildings and their immediate environment are one of the major considerations in planning for, responding to and recovering from disasters. If a building fails during a disaster event then the people inside the building are in danger and goods are likely to be damaged or destroyed. Processes have been developed over time to reduce the risk of failure of buildings in disasters, many of these embedded explicitly in building codes and standards and implicitly in zoning for permitted development types.

The disaster cycle (Figure 1) with its four stages:

1. Prevention and mitigation
2. Preparation
3. Response
4. Recovery

provides a simple model on which to base a discussion of disasters and their impact on buildings.

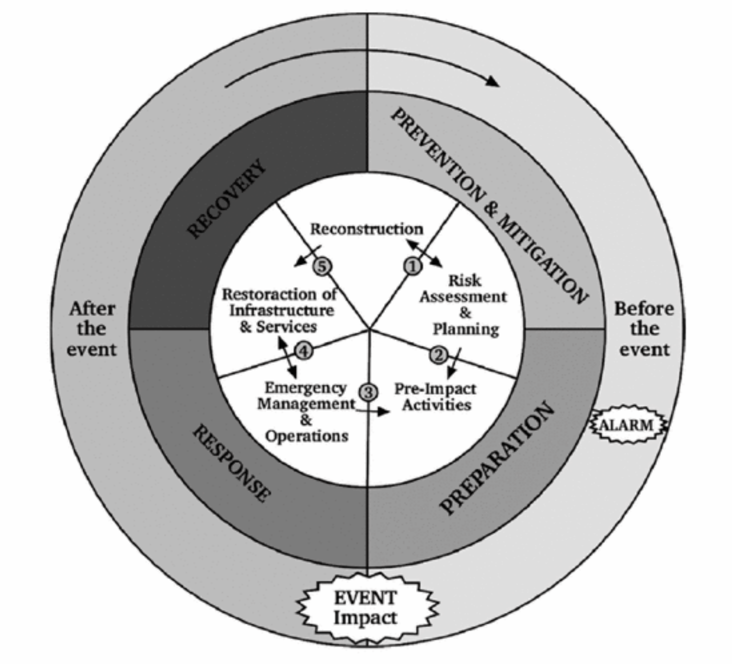
The central argument of this paper is that the use of BIM (Building Information Modelling) and open standards will improve the ability of society to reduce the impact of disasters, prepare and respond to disasters and then to recover from a disaster.

2. BIM

The term BIM (Building Information Modelling) has recently gained international prominence. It is used to describe the emerging generation of software that is being developed to support the AEC-FM (Architecture, Engineering, Construction, Facility Management) industry. The use of BIM software and methods is now being mandated by various jurisdictions internationally. As examples, the following governments or government bodies do or will be, requiring the use of BIM - the UK government, the GSA (owner of all US federal government public buildings), Senate Properties in Finland, Danish state clients. Some Australian bodies are also moving in this direction such as NSW Health Infrastructure and the Department of Defence.

As BIM has gained in prominence the term has come to mean many things, depending on the goals of the particular marketing department. For the purposes of this paper BIM is defined as *the working methods and software systems used to create virtual representations of buildings and infrastructure to support their design,*

Figure 1: The Disaster Management Cycle, PSC Forum as referenced in [1]



construction, operation and re-use/recycling, across all of the relevant disciplines. The relationship between people and their working methods is a key part of this definition. This definition supports the sharing of information amongst the stakeholders involved in proposing new building and infrastructure projects, designing, constructing and managing these facilities and eventually demolishing them. The needs of stakeholders further down the supply chain are considered by early stakeholders. Each stakeholder can view and manipulate the information about the facility in ways most appropriate to them for the current stage of development of the proposed facility. For example, a structural engineer will have full access to the BIM and will be able to modify the model down to the lowest level of detail. During planning approval stage, members of the public would be able to examine a three dimensional representation of the facility in its surrounding context.

The development of standards to support the multi-disciplinary aspects has lead to the definition of MVDs (Model View Definitions)[2]. These are explicit statements of the information that is needed by particular disciplines for a process at a particular state of use of the BIM and the outputs of that process. Examples of the types of MVDs that would be necessary to support disasters would include:

1. Prevention and mitigation
    a. Selection of internal construction and finishes to reduce the impacts of water ingress;
    b. Selection and design for appropriate wind speeds, flooding conditions;
    c. Design of connections to withstand repetitive load cycles;
    d. Ensuring that the building or structure is maintained at a level so that it can support the design loads.
2. Preparation
    a. Securing large areas of glass to reduce the risk of breakage and shards;
    b. Clean gutters and stormwater systems;
3. Response
    a. Access to structural information on damaged structures to assess risk for rescue crews;
    b. Access to data on construction types to assist in selection of equipment to assist in rescue operations;
4. Recovery
    a. Access to pre-event, “as existing” information on the building for damage assessment;
    b. Access to initial design requirements when considering if a badly damaged structure should be replaced or a new structure built elsewhere.

2. OPEN STANDARDS

The previous mention of open standards is recognition that buildings and infrastructure have expected lives that exceed that of companies that sell software. If the proposals within this paper are to be realized then the information about a building must be maintained and available through the life of the building. The genesis of open standards lies in the 1970’s when the US Navy was embarrassed to find that the CAD vendor, whose software had been used to document their assets, had gone bankrupt. This lead to the IGES standard, then the STEP standards which cover engineering in general, and finally in 1995 the development of the IFCs commenced[3]. The IFC standard has gained traction within industry in the early 2000's and is rapidly becoming the standard method for describing buildings.

This paper will consider two open standards, the Industry Foundation Classes (IFCs) published by buildingSMART[4] and CityGML published by OGC[5]. The two standards are alike in many ways:

1. They are structured similarly, with semantics, geometry, topology, the ability to store multiple representations and extensible;
2. They are semantic standards, each supporting a rich data model defining the objects of interest;
3. Geometries are spatial properties of objects;
4. They support containment hierarchies – a cadaster/site contains buildings, building contains walls, walls contain openings;

The major difference between the two standards lies in their scope[6]. CityGML defines objects from the city level down to openings in walls, while the IFC only handles cadasters (sites) down to the individual building component level, such as beams, slabs and walls.

Other differences can be summarized as:

1. CityGML uses global coordinates, IFC uses relative coordinates. As a consequence, IFC also supports multiple placement of "library" objects;
2. CityGML has the formal concept of Level of Detail (LOD) which supports the explicit definition of geometry within one object to be displayed for different purposes;
3. IFC has richer geometry capabilities, supporting full 3D geometry rather than surface modeling;

As will be demonstrated in subsequent sections, both IFC and CityGML are needed if all of the information required to support disaster response for buildings is to be accessible in open standards formats. There is work underway to provide interfaces or integration between these two standards which will eventually simplify this process[7].

4. USING BIM TO SUPPORT DISASTER RESPONSE

Responding to a disaster often requires a range of technologies and the merging of information from a wide range of disparate sources. When it comes to analysing the potential effect of disasters on buildings we need to know about the usage of the building, the construction of the building and the surroundings of the building. The long history of failures of buildings, up to the recent building collapse in Dhaka, Bangladesh, makes depressing reading. Many of these collapses would have been avoided if current knowledge had been applied. Modern building and planning codes specify the requirements for developments and structures under appropriate risk management methods. Several scenarios will be used to describe the impact of these for particular disaster types, using relevant Australian codes and data. While there will be differences in other countries these examples will serve to illustrate the key concepts of this paper.

Building and infrastructure procurement follows a well-defined path. The following breakdown is appropriate in this context:

1. Pre-design – defining the need for a development, setting the overall design requirements, identifying possible locations and selecting the final location;
2. Design – designing a structure to suit the requirements. This will need to meet the relevant regulations, codes and standards;
3. Construction – erection of the structure, with its consequent temporary works;
4. Operation – managing the structure during its operational life, including repairs and maintenance;
5. Demolition – removal of the structure, together with the consequent temporary works.

The potential for a natural disaster must be considered at each stage of this lifecycle. A partially constructed building needs to resist the effects of a natural disaster in the same way as a completed building. The possibility of a partially constructed structure becoming a man-made disaster, such as the I-35W Mississippi River bridge also needs to be considered.

(1) Prevention and Mitigation

BIM has a significant role to play in prevention, through locating new facilities to minimize risk, and mitigation, in assisting the design and maintenance of structures to appropriate standards.

The Driver District Centre (now Palmerston Senior College) was opened for students in 1986. It was intended as a joint high school and community use facility. It is located in Palmerston, a satellite town of Darwin, the capital of the Northern Territory, Australia. Darwin has been subject to two types of major disasters – the bombing of Darwin on February 19th 1942, with subsequent bombing raids through World War II, and a series of cyclones (typhoons). The most recent major cyclone was Cyclone Tracey, which struck on Christmas Eve 1974. This caused extensive damage to the city and killed 71 people. It has also experienced several earthquakes, centred to the north in the Timor Sea and to the south around Tennant Creek.

The school complex (Figure 2(a)) is located in amongst detached housing (12°29'44.18"S, 130°58'19.42"E), which is typical of Australian suburbs. The major shared facilities were the library building (Figure 2(a): black border) and the sports hall (Figure 2(a): red border). The sports hall was also designed to act as a cyclone shelter for the area.

Figure 2: Driver District Centre

Prevention of damage from cyclones is not economically feasible. Wind is pervasive. However, levels of risk can be addressed. The experience of Cyclone Tracey has meant that there are community cyclone shelters located at strategic locations throughout Darwin and its surrounds. These locations could be planned at the CityGML scale and located using relatively standard GIS queries. The design of buildings to resist cyclones is subject to the Australian National Building Code which references AS 1170.2 Structural Design Actions Part 2: Wind Actions. Under the current provisions of the Australian National Building Code, the library building would be of *importance level* 3, while the sports hall/cyclone shelter would be of *importance level* 4. This means that the sports hall would have to be designed for double the *annual probability of exceedence* of the library building.

The use of BIM to support the design of buildings, such as the sports hall, which are subject to stringent requirements, provides the opportunity to explore a wider range of options and to also develop better solutions through reducing the time required to exchange data between architectural and structural representations of the building and the structural analysis software.

The risk from storm tide can be controlled. Storm tides occur when a cyclone or other strong wind event moves across water towards a shore. The wind speed and possibly reduced air pressure forces the sea water to a higher level than it would otherwise reach (Figure 3). They are of the most concern when the cyclone coincides with a king tide event. They are much more damaging than riverine flooding due to the accompanying high winds, wind driven waves and wind and water driven debris.

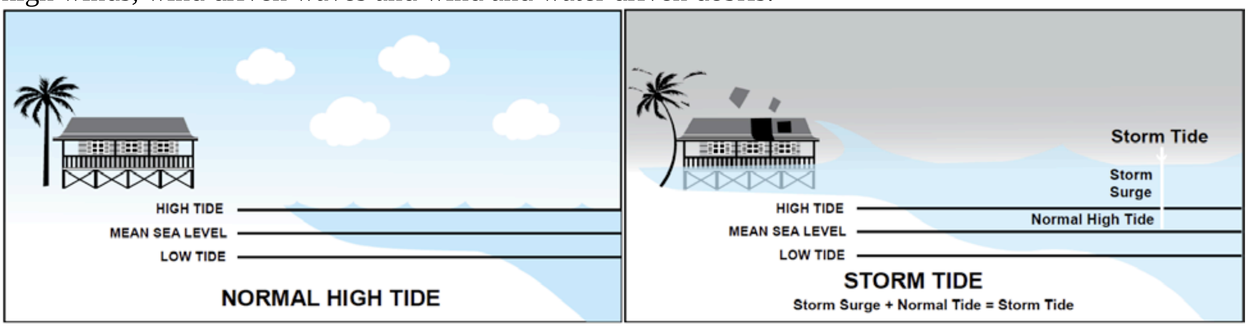


Figure 3: Storm tide (storm surge) effect[8]

The impact of storm tide during Cyclone Yasi is shown in Figure 4.

Figure 4: Houses at Tully Heads. Red ring marks position of house demolished by storm tide. Courtesy of Cyclone Testing Station, James Cook University[9]

The best approach to controlling storm tide is not to build in high risk locations. This is not an issue for the Palmerston area around the Palmerston Secondary College, indicated in the yellow square, which is well outside of the areas at risk of storm tide (Figure 5(a)). However, there is some subdivided land that is subject to storm tide (blue) to the west of the College. The design criteria for any buildings located in this area will be much more stringent that for those on less risky locations. This will include constructing the walls to reduce wave forces and impact from water driven debris and raising the floor level above the likely height of inundation. BIM, at the IFC level, can once again assist in designing more resilient structures.

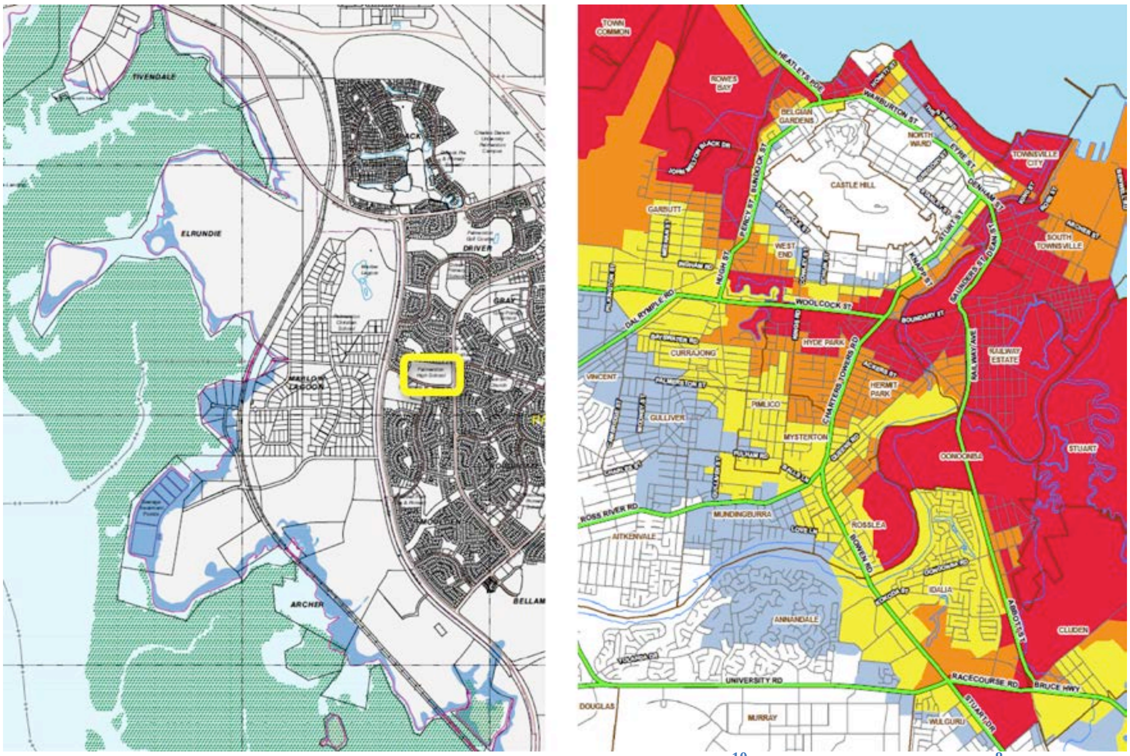


Figure 5: Tide surge maps for Palmerston NT (a)[10] and Townsville, Qld (b)[8]

It is often not possible to avoid tide surge. Cities and towns are often located in areas that suited economic development rather than being concerned about the risk and impacts of disasters. Townsville, in north Queensland, Australia was built at the mouth of the Ross River as it provided good anchorage for sailing ships and a direct route to the Charters Towers goldfields by avoiding the Burdekin River. Unfortunately Townsville is located on a low lying, relatively flat topography. Figure 5(b) shows tide surge zones for 1m (red), 2m (orange), 3M (yellow) and 4m (light blue) surges. This covers the major areas of Townsville including the CBD. Access to this level of detail of geo-spatial information can be provided through BIM at the CityGML level.

One development in this area that would have a significant impact on both the construction industry and real estate would be the ability to access hazard data for specific locations from a single source and overlay this over maps. This would assist the public in understanding the risk factors of a building they were about to buy or lease. It would also lead to efficiencies in the design, construction and management of buildings and infrastructure in reducing the time required to access this information. The technology to deliver this is available. Much of the required information is available, such as flood maps for Brisbane[11]. What is needed to merge this information with BIM?

(2) Preparation

There are both long term and short term considerations with preparation for disaster. BIM capabilities can assist in long term planning issues by providing support for planning responses to scenarios built around potential future events. This has been exploited in virtual environments[11]. While a virtual environment can simulate an entire scene this often has a sense of unreality. Augmented reality systems, where computer images can be inserted into real environments can give an improved sense of reality and allow movement within the environment. Both of these types of environments use specifically developed representations of the scenes that they are representing. There is no reason why BIM data could not be used directly in creating these environments for realistic training.

Long term planning can also include identification and dissemination of access and escape routes (lime green routes in Figure 5 (b)).

Since buildings are used for shelter during disasters it is important that they perform as required by the building regulations. This requires adequate, regular maintenance. The results of inadequate maintenance are shown in Figure 6 where the roofing purlin has rusted and the roof sheeting has been blown away. BIM provides methods to notify owners and facility managers when maintenance activities are due to reduce the incidence of such failures.

Figure 6: Detail of corrosion of top hat batten, courtesy of Cyclone Testing Station, James Cook University[14]

(3) Response

For some types of events, such as flood or cyclone, BIM is of little use during response activities. For other types of events, such as structural collapse (potentially caused by a range of events) or fire then BIM can play a critical role.

The recent building collapse in Dhaka provides a current example of how BIM could be used in the case of structural collapse. Figure 7 gives an overall view of the site of the disaster. The key questions here are if there were an up-to-date BIM of the building and this could be used to inform structural analyses would this improve response times by giving more confidence to rescues to remove debris to access victims and would this improve safety for the response team?

Figure 7: Dhaka Savar Building Collapse. http://flickr.com/photos/40831205@N02/8731789941

If a fire alarm was activated in a building for which BIM was available and there were live data feeds from the various smoke and heat sensors in the building, then this could be used by the fire brigade in planning how they would attack the fire while they were still in transit to the location. Feeding the time series data as the fire developed would allow plans to be revised if the fire behaviour changed and could also provide indications of the fire load in the building. This would then support rapid deployment as soon as fire crews arrived and could be used to assist in planning the next stages of fire control. Walder et al[13] also report studies on using indoor positioning systems to track responders in buildings. BIM would provide a context to support such tracking.

(4) Recovery

The Australian Emergency Management Handbook Series, Handbook 2, Community Recovery states "*Successful recovery relies on:*

1. *understanding the context*
2. *recognising complexity*
3. *using community-led approaches*
4. *ensuring coordination of all activities*
5. *employing effective communication*
6. *acknowledging and building capacity*."

The availability of BIM would assist in the rapid assessment of damage to existing buildings, structures and infrastructure after a disaster (factors 1 and 2 above). A comparison of what remains with BIM representing the pre-disaster structure could provide input to a range of analysis tools to speed up the assessment process. For example, the house shown in Figure 8 will need to be rebuilt at least from the floor up.

The ability to see 3D visualisations of the environment both pre- and post-event would also assist in community-led response since many people have difficulty in reading maps and plans. This would also assist in coordination between groups who are working on different aspects of the recovery operations by providing a visual means of identifying and sharing spheres of activity and clearly delineating tasks. The ability to avoid scheduling activities by two groups simultaneously at one location would also be improved by using "location-based planning" methods. All of these assist in improving communication as a whole. The issue of building capacity has already been discussed within the context of virtual and augmented environments to assist in training. These could also be used to inform crews of the expected conditions before arriving at a particular location.

Figure 8: Effect of large scale debris on house. Courtesy of Cyclone Testing Station, James Cook University[9]

BIM linked with definitions of the system requirements could also provide support to decisions about whether infrastructure should be repaired or replaced. Ideally the BIM would interface directly with analysis software to allow rapid assessment of the implications of alternatives against requirements.

(5) Process

There are a number of changes to current processes that need to be addressed before the ideas discussed in this paper can be addressed. The goal of these changes is to ensure that the information available to disaster responders is up-to-date and accurate. The use of BIM in the design of buildings and infrastructure is progressing, with its use in construction lagging slightly. Use of BIM within operations/FM is still in the early stages of adoption. The ability to integrate the changes that maintenance and upgrade processes make between BIM and FM systems is poor.

This leads to consideration on what drivers will encourage these changes. Some uses of BIM are underway now through normal technology uptake processes. Currently in Australia this is being driven by organisations, which recognise the advantages of the BIM approach. Requirement by governments or government bodies, as is occurring in USA, UK, Finland, Denmark and Singapore, would certainly encourage uptake but this is unlikely in the current political environment. Another possible driver is the insurance industry. If they can be persuaded that the integration of BIM in their processes would reduce their expenses then reductions in premiums for building owners who provide rich data for risk assessment, response and repair may provide some impetus for change.

4) CONCLUSIONS

The usefulness of BIM in supporting disaster response has been discussed through all stages of the response process. The potential benefits are clear. However, significant changes in the way that buildings and infrastructure are procured and maintained will be required before all of the potential benefits can be achieved. The key enablers are:

1. The ability to handle both geo-spatial data and detailed representations of buildings and infrastructure within a unified user interface;
2. The definition of appropriate “views” of the information for the stakeholders at the various stages of project procurement and through its lifecycle;
3. Requirements for submission of BIM during the procurement of projects;
4. Access to updated BIM in the event of a disaster;
5. Software systems available to responders to support decision making during all four stages of the disaster cycle.

None of these are insurmountable problems given the current state of technical usage in the industry. The speed and scope of uptake will depend on legal and business drivers that encourage improvements in technology and the organisations that exploit the technology.

ACKNOWLEDGMENT

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