COUPLING INNOVATIVE TECHNOLOGY, SPACE MANAGEMENT AND BIM PROCESSES WITH SMART CITY MANAGEMENT: CONGESTED CONSTRUCTION SITES IN URBAN CENTRES IN CAPE TOWN SOUTH AFRICA

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This paper examines the issue of limited space on congested building construction sites in the Cape Town urban centre. It is argued that the use of Building Information Modelling (BIM) and innovative technology will mitigate the problem of space during construction. The slow uptake by construction firms in using this technology is due to a lack of demand for digital information by clients. Building information generated during and after construction coupled with smart city development will provide the incentive for construction firms to invest in these technologies. Smart city management and big data-infrastructure is becoming increasingly important in world cities like Cape Town. The increase in demand for digital information will require building construction firms to focus more on models that encompass an entire city rather than just building-focused models. Quantitative survey methods are used to obtain information from building project managers, registered contractors as well as consultants within the central business district of Cape Town metropolis. The data obtained was analysed using SPSS statistical software. A lack of space was identified as the most significant challenge during building construction projects in the urban centre of Cape Town. The safe movement of materials on site, limited storage space for materials and restricted access for delivery of materials were found to be the most challenging aspects. The suggested ways of dealing with these issues are 'just-in-time' delivery of materials, lean construction methods and the use of innovative technology. Innovative technology includes location awareness equipment, point cloud laser scanning, bar coding, aerial drone imagery and closed circuit TV. The process of using BIM for generating and managing digital information was highly recommended for all stages of the building project from initiation to planning, execution, monitoring and finally closing. Despite the enthusiasm shown by construction personnel construction firms remain reluctant to invest in these technologies. This relates to a lack of demand by clients resulting in the risk of over capitalising and unnecessary development of personnel skills.

Keywords: space management, BIM, smart city, congested construction sites

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INTRODUCTION

Building construction firms in the developing world have been broadly criticised as not embracing innovative technologies during construction. This is particularly evident on congested construction sites in urban centres where technology can significantly mitigate problems associated with space (Pinfold, 2015). The reason for not investing in new technologies is the risk of over capitalising and the unnecessary training of personnel (Jin *et al*., 2017). During the procurement process the client's needs underpin the objectives of the project. If there is no need for technologically advanced construction processes then there isn't an incentive for a construction firm to introduce them. The main priority when procuring building construction projects is early completion of the project, price competition and risk mitigation.

One of the advantages of BIM is sharing building information and providing virtual simulation of construction processes (Isikdag, 2015:34). BIM encourages collaboration between project team members which means the project is more likely to achieve a successful outcome. Therefore, from a contractor's perspective, BIM and related technology should present an opportunity for better success in a project. However if construction firms are not interested in engaging with BIM and related technology they're not going to advise the client to use BIM. The South African BIM institute conducted a survey in 2016 investigating why South African building construction firms are reluctant to implement BIM.

The survey revealed that construction firms are following trends rather than taking the lead in BIM implementation. A large percentage of respondents in the survey (81%) were concerned that there is no local mandate by the National Department of Public Works concerning BIM standards (Harris, 2016:4). In South Africa BIM implementation has had some success however is not yet an industry standard. The potential use of BIM in today's construction industry is gaining momentum and will reach a tipping point sometime soon. Contractors, subcontractors and suppliers who want to tender for projects that include BIM must understand the requirements of BIM and related technologies and have the capacity to implement it. Construction firms that do not embrace new technology will lag behind and lose their competitive edge (Pinfold 2015:58; Hardie 2010:387).

This paper examines the issue of limited space on congested building sites in the Cape Town urban centre and to what extent construction firms are using BIM and related technology to address space issues. The author argues that the use of BIM and related technology can mitigate the problem of space during construction. A survey was conducted to establish what construction personnel considered the most significant challenges on congested building sites in urban centres and what broad-minded management methods are being used to mitigate these challenges. Finally the author considers future developments of BIM and the influence it will have on construction firms. It is suggested that construction managers embrace the digital revolution gripping the construction industry and couple innovative technology, space management and BIM processes with Smart City Management.

INNOVATIVE TECHNOLOGY

According to Pinfold (2015:1) the use of innovative technology can significantly mitigate problems related to the management of space on a construction site. Location awareness technology for instance identifies position in real-time using Global Positioning System (GPS) and Wi-Fi technology. Location awareness technology

consists of indoor and outdoor location sensors that can be downloaded on mobile handheld devises such cell phones, tablets, data loggers and watches. Location awareness technology allows both onsite and offsite monitoring of materials (Razavi *et al*., 2012:239). Aerial photography using drones is an effective method to monitor space outdoors. Weakly surveys can be done quickly and cheaply to identify problem areas. CCTV cameras can be used inside and outside the building to provide explicit recognition of conditions on site.

Manual Data Collection and Barcode Scanning

Manual data collection on-site is a task that is nearly impossible when recording on-going construction work (Yun-Yi Su 2010:4). As a result only approximate estimation of work can be collected with undesirable accuracy. Barcoding of materials, machines and tools provides real-time information about their status. Personnel can scan the barcode using a smartphone camera to access information from an inventory database via an internet application. When an item is 'on the move' the inventory can be consciously updated to reflect its current location, when it is expected to arrive on site or where it is. Material tracking provides critical information needed by the construction supervisor in order to manage delivery. Crane time (crane waiting) can be better managed so that materials are immediately hoisted to their required location on arrival rather than having to be stored on site.

Efficient material monitoring enables 'just in time' delivery of material which can reduce the need for material storage. A barcode attached to an item or packaging can be updated by personnel on site by scanning the code and entering new information in the inventory such as its new GPS coordinates. Knowing the rate at which materials are arriving and the rate at which the materials are being used is an important aspect of lean management. Yun-Yi Su (2010:7) highlighted the importance of timely and accurate feedback information which describes actual operational data on the construction site. Without timely and accurate feedback, the accuracy of the updated project database is effected hence many critical decisions cannot be made (Davidson and Skibniewski 1995). The monitoring of materials and optimising supply chain management is critical in managing the delay between procurement and its arrival on site. The rate at which material is received is seldom the same as the rate at which the material is used. Barcode scanning in this case is useful for balancing surplus and demand of items.

Monitoring and Measuring on Site

Unnecessary movement of material on site constitutes wasted time. Multiple moves of stockpiles or clearing materials out of the path of machinery is a result of a poor site layout and space management. Location awareness technology, CCTV cameras, drone imagery and barcode scanning technology can be effectively used to monitor and make sense of unnecessary movement. Another cause of wasted time is waiting for design details from engineers, architects and construction personnel. Becker (2015:66) identified laser scanning as one of the most exciting technologies to have emerged in the construction industry. It is widely accepted that laser scanning is useful for measuring existing building structures that are difficult to get to (Gleason 2013:2; Tuttas *et al*., 2014:341; Kim *et al*., 2013). The use of laser scanning can result in large and complex datasets that need to be deciphered by skilled personnel. Isikdag (2015:34) refers to BIM as a methodology related to sharing of information in real-time over the internet. BIM can be used as a space linker that links macro and micro spaces. With the use of location awareness technology fully interactive BIM

can be introduced on site. BIM allows the flow of 3D spatial, financial and material information to be seamless between the field and office.

Futuristic Development of BIM and Digital Technology for Building Construction Projects

Construction projects stall and falter without information. When implementing BIM on a building project it creates a vast amount of free flowing standardised information that can be utilised by other related infrastructure projects such as transport systems and utilities. Technology available today can produce vast amounts of useful information generated on building construction sites either for batch processing or real-time processing. Data mining of pre-existing databases provides knowledge that can be effectively used to organise resources. Vast amounts of real-time data are first stored then processed in Big Data repositories and infrastructure before being streamed for use by the construction firm.

Ismail (2016:1) refers to the so-called "5V" in Big Data: volume, variety, velocity, veracity, and value with an emphases on volume, variety and velocity. Volume, variety and velocity indicates huge amounts of data acquired constantly which become very difficult to store and process. If Big Data is used and communicated in a disciplined manner then decisions made will be enhanced based on multiple data sets that are current and accurate. At present a single BIM model used for design, evaluation and planning cannot make use of unstructured information and Big Data infrastructure. However if BIM is expanded from a single building model to include buildings and infrastructure in an entire city, where geo-referenced buildings and real-time information are linked, then BIM models can be converted and contribute to Smart City models.

Khemlani (2015) refers to the expansion of BIM to include infrastructure with the next logical step being City Information Modelling or Smart City Modelling. Khemlani describes City Information Modelling as the connection between BIM (buildings) and other related city infrastructure such as roads and public spaces (open data), streetlights (sensors) and even people (social media). A BIM model is traditionally centred on information while a Smart City model is centred on the flow of information. The author believes the extension of the BIM model to a Smart City model in South Africa is not far-fetched and suggests that building construction managers should be looking beyond BIM level 1 and 2 to BIM level 3, smart city management and Big Data analytics. BIM level 3 is the integration of electronic information with full automated connectivity and web storage. BIM Level 3 proposes a construction industry that is smarter and more digitally-enabled than BIM level 2.

THE CAPE TOWN URBAN CENTRE SURVEY

Design, Methodology and Approach

In 2015 a quantitative survey was done in the Cape Town city centre to investigate to what extent construction personnel support the use of innovative technology on congested construction sites (Pinfold, 2015). The sample consisted of building project managers, registered contractors as well as consultants working on three construction sites in the Cape Town city centre. The three building sites included the Standard Bank Towers worth 500 million Rand, Cape Town Convention Centre worth 832 million Rand and Portside worth 1.6 billion Rand. The building projects were all in their final year of construction.

In 2018 a similar survey was done to investigate to what extent BIM and related technologies are being used on building construction sites in Cape Town. The sample for the survey consisted of building project managers, registered contractors as well as consultants working on the Dido Valley Multipurpose Building Project in Simon's Town in the Cape Town Metropolis. The project is worth 168 million Rand and is in the first stage of construction. The selection of the Dido Valley Multipurpose Building Project was based on the scope of work and the relationship the Department of Construction Management and Quantity Surveying at the Cape Peninsula University of Technology (CPUT) has with the contracted construction firm. The construction firm is considered progressive in its management approach and regularly employs students and degree graduates from the Department. These students/graduates are well rehearsed in technology and BIM capability. Respondents were asked if they had any experience using these technologies in the past and if they intended using them on this project. The objective of the survey was to reveal any uptake in the use of technologies that were identified as useful in the 2015 survey. Respondents were also asked to indicate to what extent space influenced production on congested construction sites and how they managed it. Twelve challenges identified during the 2015 survey were listed on the questionnaire that might influence production on a congested construction site. Five management strategies identified during the 2015 survey were also listed on the questionnaire.

The Perception of the Usefulness of Innovative Technology

The technologies identified in the 2015 survey included BIM, point cloud scanners, remote sensing imagery obtained from a drone, location awareness technology, bar code scanning and CCTV monitoring. Respondents were asked how effective these technologies are during construction. A sample of 139 questionnaires was obtained from construction personnel in the city centre. BIM was perceived to be the most useful technology across all five building production processes. Although construction personnel believed that BIM and other technology significantly enhances building production processes only a few believed it was a good investment for the firm they worked in. Respondents blamed the lack of BIM standards in the construction industry as a major stumbling block for BIM implementation. Respondents agreed that the construction industry needs to be encouraged to convert from paper documentation to digital information systems (see Table 1).

Table 1: Perceived usefulness of innovative technology. Source Pinfold 2015

	Process groups in building production management				
Innovative Technology	(a) Initiating	(b) Planning	(c) Executing	(d) Monitoring	(e) Closing
1. BIM technology	Y	Y	Y	Y	Y
2. LAT technology	N	N	Y	Y	N
3. Point Cloud technology	N	N	Y	Y	N
4. Barcode Scanner technology	N	N	Y	N	N
5. UAV technology	N	N	N	N	N
6. CCTV technology	N	N	N	Y	N

The Use of Innovative Technology

The 2018 survey included 22 construction personnel currently employed on the Dido Valley Multipurpose Building Project. The distribution and collection of questionnaires was facilitated by selected practitioners. The 22 respondents consisted of 4 (18%) females and 18 (82%) males, their ages varied between 45% above 50, 18% between 40 and 50 and 36% younger than 40. Respondents were asked to what extent each technology was being used on site and if they had used the technology before. A five-point scale was used where 1 = 'not at all', 2 = 'sometimes', 3 = 'often', 4 = 'generally', and 5 = 'almost always'. Of the respondents 27% had often used CCTV on building construction sites, 9% occasionally and 64% never. 18% of respondents said BIM was more often than not used for construction projects, 18% said it was seldom used and 64% said it was never used. 18% had used location awareness technology, 27% occasionally and 55% never. 9% had occasionally used barcode scanners and 82% had not. 18% had used a laser scanner however 82% had not. None of the respondents had used or seen a drone being used on site (see Table 2).

Table 2: The use of innovative technology on congested sites in the Cape Town central city

Innovative Technology	Scale1	Scale2	Scale3	Scale4	Scale5
CCTV technology	64%	9%	27%	0%	0%
BIM technology	64%	18%	18%	0%	0%
LAT technology	55%	27%	18%	0%	0%
Bar Code Scanner technology	82%	9%	9%	0%	0%
Laser Scanning technology	82%	18%	0%	0%	0%
UAV technology	100%	0%	0%	0%	0%

The Challenges Experienced on a Congested Construction Site

Respondents were asked to indicate what challenges they had on congested building sites, using a five-point scale, where 1 = 'not at all', 2 = 'sometimes', 3 = 'often', 4 = 'generally', and 5 = 'almost always'. Safe movement of materials on site, limited storage space for materials and restricted access for delivery of materials were found to be the most challenging aspects (see Table 3).

Table 3: Challenges experienced on congested construction sites in Cape Town central city

Challenges on a Congested Site	Scale 1	Scale 2	Scale 3	Scale 4	Scale 5
Safe movement of materials around site	0%	0%	9%	91%	0%
Limited storage of materials on site	0%	18%	18%	64%	0%
Restricted access for delivery of materials	0%	18%	27%	55%	0%
Coordination management issues	0%	9%	82%	9%	0%
Locating material on site	0%	18%	73%	9%	0%
Health and safety issues	0%	0%	64%	36%	0%
Congested space on site	0%	9%	64%	27%	0%
Restricted access for delivery of materials	0%	0%	55%	45%	0%
Difficulty communicating on site	0%	27%	55%	9%	9%
Damage to material on site	0%	36%	55%	9%	0%
Personnel in close proximity to machinery	0%	36%	36%	27%	0%
Overcrowding of personnel	0%	82%	18%	0%	0%

The Management Response to the Challenges on a Congested Construction Site
Respondents were also asked to indicate how often construction management methods were used to deal with challenges on congested sites, using a five-point scale, where 1 = 'not at all', 2 = 'sometimes', 3 = 'often', 4 = 'generally', and 5 = 'almost always'. The suggested ways of dealing with these issues are 'just-in-time' delivery of materials, lean construction methods and the use of innovative technology (see Table 4).

Table 4: Management response to the challenges on congested construction sites in Cape Town central city.

Management Methods	Scale1	Scale2	Scale3	Scale4	Scale5
Just-in-time delivery of materials	0%	0%	27%	73%	0%
Lean construction methods	0%	27%	64%	9%	0%
Knowledge management	0%	9%	45%	27%	18%
Prefabrication	0%	27%	36%	36%	0%
Use of innovative technology	0%	36%	27%	36%	0%

FINDINGS

The 2015 survey showed that construction personnel believed BIM and related technology have the potential to mitigate challenges experienced on congested construction sites. However the 2018 survey shows that BIM and related technology are seldom used. Construction personnel identified movement of materials on site, limited storage space for materials and restricted access for delivery of materials as the main challenges on congested construction sites. Just-in-time delivery of materials, lean construction methods and the use of innovative technology were identified as the main management strategies used to mitigate these problems. Despite the enthusiasm shown in the 2015 survey there is little evidence that BIM and related technologies are being implemented on building construction projects in the Cape Town Metropolis urban centres.

CONCLUSIONS

The core underlying issue that was identified as being problematic on a congested construction site is the lack of space and overcrowding of workplace. This is consistent with other surveys where space management is widely accepted as the most critical aspect on congested sites (Tommelein and Zouein 1993; Spillane *et al*., 2011:143). The 2015 survey found that BIM was highly recommended for all stages of a building project from initiation to planning, execution, monitoring and finally closing while other innovative technology were believed to be useful only at certain stages in a building construction project. However the 2018 survey indicates limited use of BIM and innovative technology on construction sites in the Cape Town metropolis. The suggested ways of dealing with congested space is through 'just-in-time' delivery of materials and lean construction methods. The surveys indicate that construction managers acknowledge the potential of BIM and innovative technology however underutilise it for management during building construction projects.

The author suggests in this paper that construction managers should be aware that BIM is gaining momentum in today's construction industry and that construction firms need to build capacity to enable them to tender for building projects that are required to utilise BIM processes. BIM should not be seen as a single model but as multiple models incorporated in a Smart City model. It is suggested that Big Data and Smart City infrastructure developments will be the catalyst needed to encourage

construction firms to invest in BIM in the long term and to contribute to its trajectory from its predominantly building-focused models to models that encompass an entire city. The South African government needs to follow this trend and invest more in Big Data infrastructure if it is to keep up with this digital revolution.

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