Framework for Productivity and Safety System using BIM in Singapore

## Abstract

**Purpose**: Despite the recognition of the importance of the construction industry in Singapore’s economy, the industry is plagued by poor safety and productivity performance. Improvement efforts by the government and industry have not yielded much results. The study proposes a framework for developing a productivity and safety monitoring system using Building Information Modelling (BIM).

**Design/methodology/approach**: The framework, Intelligent Productivity and Safety System (IPASS), takes advantage of the mandatory requirement for building plans to be submitted for approval in Singapore in BIM format. IPASS is based on a study comprising interviews and a questionnaire-based survey. It uses BIM to integrate buildable design, prevention and control of hazards, and safety assessment.

**Findings**: The paper illustrates the development of IPASS that is able to generate productivity and safety scores for a construction project by analysing the information in the BIM models.

**Research limitations/implications**: The paper demonstrates that BIM can be used to monitor productivity and safety as a project progresses, and help to enhance performance under the two parameters.

**Practical implications**: IPASS enables collaboration among project stakeholders as they can base their work on an analysis of the productivity and safety performance before the project starts, and as it progresses. It is suggested that the BIM same model submitted to the authorities should be used for the IPASS application.

**Originality/value**: IPASS has rule-checking, hazards identification and quality checking capabilities. It is able to identify hazards and risks with the rule-checking capabilities. IPASS enables practitioners to check mistakes and the rationality of a design. It helps to mitigate risks as there are built-in safety measures/controls rules to overcome the problems caused by design deficiency, wrong-material-choice, and so on.

## Keywords: BIM, monitoring, productivity, safety, system

**Paper Type:** Research article

# Introduction

The Singapore government is well known for its formulation of a long-term vision and planning for the individual industries and the economy as a whole (Henderson, 2012; Ofori, 2002; Yuen, 2011;). In the construction industry in particular, following the recognition of its role in long-term economic and social development, the government plays an active role through strategy and policy formulation, regulation, direct administration and provision of incentives to ensure its improvement and well-being. The construction industry in Singapore has benefited from the government’s understanding of its strategic importance, and its commitment to nurture a strong and competitive local industry (Low, 1992; Kumaraswamy *et al.*, 2010; Ofori and Lim, 2012). This leadership and active involvement has led to the transformation of the industry to one which builds highly complex items in challenging physical environments, using advanced technologies and systems. However, the industry’s performance in productivity and safety remains poor. Annual records show that construction almost consistently reports the lowest level of productivity growth per annum. Moreover, the construction industry has the highest level of workplace mortality among all the industries (Ofori, 2012).

Among the current policy priorities of the Singapore government for the construction industry are the enhancement of productivity (BCA, 2015c) and safety (WSH Council, 2015) performance, as well as the optimal strategic application of information and communications technology (ICT) (BCA, 2015a). A range of initiatives has been launched to provide guidance and support in each of the three areas. Considering this national focus, it is pertinent to investigate how the ICT applications could be utilised in the effort to enhance productivity and safety performance in construction.

Taking the two issues, productivity and safety, together, it can be stated that the decades-long efforts to realise improvement of Singapore’s construction industry in these two areas have not yielded much results for several reasons. Among these are: (i) the large number of inter-related factors which contribute to performance levels in each of the areas; (ii) the nature of the structure of the construction industry itself; and (iii) the influence of factors outside the project and the construction industry which are beyond the control of the practitioners (Teo et al., 2014). The construction industry should think of new means and methods of production to enhance productivity. It should also improve its safety levels and reduce the many adverse effects of its poor safety performance.

***Aim and objectives***

The aim of the study is to investigate the potential of utilizing Building Information Modelling (BIM) in the effort to improve the productivity and safety performance of the construction industry. This aim is relevant as it is now a compulsory requirement for prospective developers to submit building plans for regulatory approvals in BIM format (BCA, 2015a). To help the industry to prepare to meet the requirement, the government has introduced a BIM capability development and investment support programme. The study would make it possible to consider how the potential benefits which could be derived from the application of BIM could be effectively increased.

The objectives of the study are to:

(i) explore how BIM can be used to improve productivity and safety performance in the construction industry; and

(ii) develop a system to monitor and improve productivity and safety throughout the project using BIM.

# Background of the Proposed System: Construction safety and productivity performance in Singapore

Productivity, at both sectoral and national levels, has always been a concern for the government of Singapore. One of the key recommendations from the Economic Strategies Committee (2010) of Singapore was that higher productivity growth of 2 to 3 percent per year would be required to enable the nation’ Gross Domestic Product (GDP) to grow by the projected average of 3 to 5 percent per year over the next decade. The challenge is even greater in the construction industry because it has long been perceived to be less productive than other sectors of the economy (see, for example, CIDB, 1992; Economic Strategies Committee, 2010). The construction industry in Singapore, as in many other countries, is unable to keep pace with the rate of technological advancements realised in other sectors, and is considered by some researchers to be facing a convergence of gross inefficiency (Smith and Tardif, 2009; Construction 2025, 2013).

Among the factors which are most often cited as contributing to relatively low productivity in construction in Singapore are: (a) reliance on a pool of itinerant, low-skilled foreign workers; (b) separation of construction from design and persistence in adoption of designs which are difficult to build; (c) reliance on subcontracting; (d) unwillingness to invest in more modern and efficient equipment owing to uncertainties in workloads; and (e) lack of interest of clients in productivity (Teo et al, 2014). Studies in other countries have found a range of factors which can be categorised as those relating to the nature of the construction industry; project management practices of the industry; availability of human resources; application of technology; and the industry’s operating environment (see, for example, Bernstein, 2003; Productivity Commission, 2014; Yi and Chan, 2014). However, in Singapore, the problems persist despite over three decades of productivity development programmes and initiatives (Ofori, 1993; Low, 2015).

One of the causes of inefficiency in construction is the productivity lost from accidents. Reduced productivity has been highlighted as one of the indirect costs of accidents (Hinze, 1994; Levitt and Samelson, 1993; Smallwood, 1999). These indirect costs are often hidden and unidentifiable (Hinze, 1994). Poor safety management may lead to accidents which may then have an adverse impact on productivity (Hinze and Appelgate, 1991; Zhang et al, 2015; Zou et al, 2015). Hence, safety and other elements of performance on site play an important role in the national push for higher productivity.

In line with the Workplace Safety and Health (WSH) 2018 vision (WSHC, 2009), which is “A safe and healthy workplace for everyone”, the Ministry of Manpower (MOM) of Singapore set a target of the national fatality rate from work-related accidents to be 1.8 per 100,000 workers by 2018. This is a challenging target considering the prevailing figure of above 2.0 over the past 10 years. The challenge is greatest in the construction industry because it has consistently contributed the highest number of fatalities each year, despite the implementation of safety improvement programmes over many decades. The workplace fatality rate for the construction industry was 5.5 per 100,000 workers in 2014 (WSH Institute, 2015). The records show that the industry has not realised much improvement in safety performance and hence, it might be the industry which would find it most difficult to attain the target. It is apparent that there is a need for a system to help the construction industry to monitor safety performance.

The BCA, together with buildingSMART Singapore, have been promoting the use of BIM as the platform to facilitate the integration of knowledge in design and construction, and handing over to facilities management. BIM offers tools to help designers and contractors to anticipate design problems during the early stages of a project; this enables them to minimise unnecessary work during the construction phase (BCA, 2015a). Hence, the BCA has identified BIM as a key technology to improve productivity and level of collaboration among, and integration across, various disciplines in the entire construction value chain (BCA, 2015a).

Given this potential, it is pertinent to consider how BIM can provide the platform for integrating the efforts towards enhancing productivity and safety performance on a construction project. According to Jung and Lee (2015), BIM has been adopted in many countries since the early 2000s but many of these nations, especially those in Asia, are not deriving the maximum benefit they could attain, considering the potential of BIM (see Table 1). Many studies showed that BIM can play a significant role to integrate risk management with the design, construction and maintenance of a project (Zou, et al, 2016) to mitigate against unsafe design problems having a negative impact on productivity. In addition, Zou et al (2016) stressed the need for a formalised system to manage risks as a huge gap in implementing BIM for risk management on construction sites still exists.

*Table 1. The averages and standard deviations of the engagement level (adapted from Jung and Lee, 2015)*

# Potential of Building Information Modelling (BIM) for Safety, Productivity and Associated Risk Management

Zou et al (2016) observed that there is a new trend towards the use of BIM and BIM-related digital tools for improving safety and risk management, as the traditional risk management method has been found to have many limitations in practice. Numerous studies (Shim et al 2012, Harmann et al 2012, Zhang et al 2014, Zhang et al 2015a, Zhang et al 2015b) have revealed that some unresolved challenges exist in the current risk management approach that is dependent on experience and multi-disciplinary knowledge. These challenges decrease its effectiveness and make it reliant on the individual skills on projects. However, as noted by Zou et al (2016), whearas any project comprises many different phases, many of the participants may leave the project after completing their work. Thus, much risk information may be lost if it is not properly recorded and communicated to other project participants.

BIM has been found to be an effective way to assist early identification and assessment of risks for design and construction through 3D visualisation (Grilo & Jardim-Goncalves 2010), 4D scheduling (Zhang and Hu 2011), and 5D cost estimating (Mitchell 2012). Sacks et al (2010) integrated Lean principles and BIM for safety planning whereas Golovina et al (2016) integrated GPS and BIM for preventing struck-by and near miss incidents between workers-on-foot and construction equipment. Some efforts that could further integrate BIM with risk management on the project’s safety performance parameter have been observed. These include: automatic rule checking (Eastman et al 2009, Zhange et al 2013, Sulankivi et al 2013), and proactive IT-based safety systems (Forsythe 2014). There are a number of marked reasons behind the increasing interest and adoption of BIM for risk management. The reasons for the interest in the application of BIM for risk management include the fact that it has been realised that all risk management methods become ineffective if any risks could not be detected before they happen (Carter and Smith 2006), and BIM assists in the early identification of risks.

AGC (2010) defines BIM as the development and use of a computer software model to simulate the construction and operation of a facility. The resulting model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data, according to users’ needs, can be extracted and analyzed to be used for decision making and process improvement.

According to Smith (2007), BIM "will make a great impact in the way a construction project is managed and will also bring along a safer jobsite" (p.12). Other benefits of BIM include faster and more effective processes; better design and quality (Azhar, 2011); being a collaboration tool for designers, project engineers, safety officers, and other project participants which can raise safety awareness of the team (Benjaoran and Bhokha, 2010); reducing much of the manual efforts; enabling the realisation of time and cost saving; improving various aspects of the performance of onsite operations (Gong and Caldas, 2011); and helping project teams to identify the likely conflicts and risks that would have arisen due to the changes in design (Gu and London, 2010).

Zuppa *et al.* (2009) studied the perception of BIM's impact on various project performance parameters including: productivity, schedule, safety, cost and quality. While noting that BIM was most frequently perceived of as a tool for visualizing, coordination, avoiding errors and omissions, and improving the productivity, schedule, safety, cost and quality of construction projects, they found that BIM had the strongest perceived positive impact on the quality, cost and schedule of construction projects among the success measures.

A number of authors have explored how BIM can be used to improve safety in the construction industry. Ku and Mills (2008) focus on design-for-safety (DfS) concepts, which include hazard analyses and risk assessments. They investigated the developments in BIM and computer tools for considering safety in the design review and simulation which may enhance the DfS process. They concluded that DfS (or Prevention through Design (PtD)) tools have the potential to support and improve designers’ knowledge and skills concerning hazard recognition. There is a need for better PtD tools that can support design and construction teams to better recognize hazards and to handle the complexity which might be introduced by specific jobsite conditions and activities.

Zhang *et al.* (2013) developed an automated safety checking platform which is able to inform construction engineers and managers of the various safety measures needed for preventing fall-related accidents before construction starts. The system automatically analyzes a building model to detect safety hazards and suggest preventive measures to users. Similarly, Benjaoran and Bhokha (2010) developed a rule-based system that is able to detect any work-at-height related hazards and propose necessary safety measures. Factors related to building components and activities such as component type, dimension, placement, working space, activity type, sequence, and materials and equipment are used as input data. These factors are examined to find any work-at-height hazards. The system is able to suggest necessary safety measures, activities or requirements.

Choi *et al.* (2014) developed a BIM-based evacuation regulation checking system for high-rise and complex buildings which allows architects, designers and owners to evaluate the design to ensure that it meets the regulatory requirements. Continuous checks are possible due to an automated system and detailed guidelines.

As compared to BIM for safety, the potential of BIM for productivity improvement has not been widely explored. Nath *et al.* (2015) use BIM to improve the workflow for precast shop drawing generation. They show that there could be an overall productivity improvement of approximately 36 per cent in processing time and 38 per cent for total time. Gelisen and Griffis (2014) note that, currently, there is no commercially available system that estimates future activity productivity by factoring in real-time information. They developed a tool which allows a company to predict, manage, and optimize the productivity associated with a project or phases of projects.

Despite the potential of BIM to improve construction project performance, many approaches focus on the improvement of safety or productivity separately. This study attempts to incorporate both productivity and safety using the BIM to manage risk and to control hazards. The study is based on the premise that productivity and safety improvement should be considered at the design stage, with BIM as a tool to facilitate it.

# Improvement of Productivity and Safety Performance in Singapore

## Productivity Improvement

To improve construction productivity, the Singapore government, through the Building and Construction Authority (BCA), has launched many programmes and initiatives since the mid-1980s. The main aim of construction productivity development programme in Singapore has been to reduce the number of workers on site and to foster the technological advancement of the industry. To achieve that, the government has mainly encouraged the industry to adopt more labour-efficient designs and the use of pre-assembled products.. Among the initiatives under the productivity development programme are: (a) provision of incentives to support mechanisation; (b) the promotion of the concept of Buildability and introduction of the Buildable Design Assessment Scheme, followed later by an equal focus on Constructability; (c) promotion of prefabrication, followed by stress on the use of larger items and volumentric pre-formed parts; (d) regulations stipulating minimum skills requirements for foreign workers; (e) focus on training throughout the industry’s workforce; (e) promotion of more integrated procurement arrangements such as design-and-build; (f) use of IT; and (g) support for application of BIM (CIDB, 1992; Ofori, 1993; Construction 21 Steering Committee, 1999; Low, 2015). The productivity drive has been guided by two strategic construction productivity plans. The vision of the first Construction Productivity Roadmap of Singapore which was launched in 2010 was to build a highly integrated and technologically advanced construction industry led by progressive firms and supported by a skilled and competent workforce by 2020 (BCA, 2011). The roadmap comprises four strategic thrusts. The first thrust is “Introducing regulatory requirements and setting minimum standards to drive widespread adoption of buildable design and labour-saving technology”. Under this thrust, it is stated that there is a need to enhance the buildability framework by requiring designers to deliver more buildable designs upstream. It is also specified that there is a need to drive the adoption of BIM, as BIM improves the co-ordination of the construction value chain and reduces rework. BCA formulated a 5-year BIM Roadmap to drive industry-wide adoption of BIM by 2015. the Key measures of the roadmap included mandating the use of BIM for regulatory building plan submissions in phases starting from 2013.

The concept of buildability helps to ensure that productivity is considered during the design stage. The Buildable Design Assessment System (BDAS) was introduced by the then Construction Industry Development Board (CIDB), the predecessor of the BCA in 1991. BDAS is a means for measuring the potential impact of a building design on the usage of labour on site. One of the main recommendations of the Construction Productivity Task Force (CIDB, 1992) was the promotion of ‘buildable design’ to achieve labour-efficient construction. Buildable design can be achieved by increasing the degree of standardisation and prefabrication of structural systems, and architectural external and internal walls.

As applied in Singapore, the concept of “buildability” focuses on the 3S Principles of Buildable Design: (a) standardisation – repetition of grids, sizes of components and connection details; (b) simplicity – use of uncomplicated building construction systems and installation details; and (c) single integrated elements – those that combine related components together into a single element that may be prefabricated in a factory.

Buildable Design Score (BD Score) is the score achieved after a building design is appraised using the BDAS. It is a point-based system under which marks are assigned for different types of components used mainly in the elements of the structural frame and external walls. A design with a higher BD Score will result in more efficient labour usage in construction and therefore higher site labour productivity. With effect from 1 January 2001, all new building projects with Gross Floor Area (GFA) of more than 5,000 sq. m. were required to meet minimum BD scores (Framework, 2000). Over the years, the minimum buildability scores have been raised progressively. From 1 January 2004, the buildability requirements were extended to cover smaller projects with GFA of at least 2,000 sq. m. Buildings with planning applications made on or after 1 December 2015 must follow the latest Code of Practice on Buildability, 2015 Edition (BCA, 2015b). The building designs were required to meet prescribed minimum buildability scores ranging from 70 to 90 (out of 100 points), depending on the building type.

# *Safety Improvement*

Safety in the construction industry has always been a concern in Singapore owing to the relatively high number of incidents and fatalities. The measures to address this have included the enactment of the Occupational and Safety Health Act (OSHA) was enacted in 2000 and the introduction of the Occupational Safety and Health (OSH) framework in 2005. An essential part of the current framework is the Workplace Safety and Health Act (WSHA), which came into effect in 2006.

The efforts to improve safety performance in construction in Singapore have been part of the national safety programme, under the Ministry of Manpower (MoM), and involving the Workplace Safety and Health Council and Workplace Safety and Health Institute. The key initiatives over the years have included: the promulgation and application of the provisions under the WSH Act and Framework; CultureSAFE, and Pledge for Zero CEO Commitment Charter. The **WSH Act** is the key legal instrument supporting the WSH **framework** in Singapore and was enacted on 1 March 2006, replacing the Factories Act. The CultureSAFE programme provides a platform for organisations to embark on a WSH culture-building journey beyond the WSH infrastructure and competency. It focuses on cultivating the right WSH mindset and attitudes in every employee in the organisation. Pledge for Zero CEO Commitment Charter is to demonstrate the commitment to implement the plans to realise the collective goal at company level, industry level and tripartite partners (company-government-trade union) level (WSHC, 2015). The safety efforts are to be intensified and accelerated to meet the ambitious target of national fatality rate to less than 1.8 per 100,000 workers by 2018 set under the WSH 2018. The proposed initiatives include: Construction Safety Audit Scoring System (ConSASS), and Design-for-Safety (DfS).

Traditionally, construction worker safety was often overlooked until the start of the construction phase (Gambatese et al., 1997) as, in many instances, it was regarded as the sole responsibility of the contractor (Hinze and Wiegand, 1992). However, Behm (2005b) and Gambatese et al. (2008) confirmed a link between design and construction safety. The concept of DfS started to gain attention in the 1990s. It is described as the deliberate consideration of construction site safety in the design phase of a construction project (Behm, 2005a). By addressing safety during the design process, hazards would be eliminated or reduced during construction (Behm, 2005a). The focus is also on reducing rework through effective project planning (WSH Council, 2015).

The DfS concept was mandated in the UK through its Construction Design and Management (CDM) Regulations; while in Australia, it was mandated through the Work Health and Safety (WHS) Act 2011 (Zou and Sunindijo, 2015). Singapore’s WSH Council launched the Guidelines on Design for Safety (DfS) in Buildings and Structures in November 2008. The guidelines highlight the need for stakeholders including the client, designers and contractors to work together to help reduce risks at source (WSH Council, 2011).

The ConSASS is a tool for measuring the maturity of the WSH system which includes the documentation and implementation. The aim is to provide a standardized scoring system for the construction industry. Since 2011, all construction worksites with a contract sum of S$30 million or more are required to have mandatory Safety and Health Management System (SHMS) audits conducted, based on the ConSASS audit checklist (MOM, 2013).

The questions in the CONSASS checklist are grouped into bands, from Band I to Band IV, to reflect the increasing level of maturity of the elements being audited. Auditors are required to audit each element of the OSHMS up till and including the Band III questions. The score attained for each band is calculated based on the number of questions satisfied as a percentage of the total number of questions in the band. Auditors may stop auditing the element should it fail to satisfy at least 70 per cent of the questions within any of the first three bands.

Each band evaluates the following:

* Band I: Whether the SHMS has a particular provision;
* Band II: Whether the content of the particular provision is sufficiently comprehensive;
* Band III: Whether the particular provision is well-implemented on site; and
* Band IV: Best practices.

The audit checklist of ConSASS is derived from audit questionnaires from the Singapore Standards for Occupational Safety and Health Management System (SS506), Code of Practice for Safety Management Systems for Construction Worksites (CP 79) and the Universal Assessment Instrument (UAI) published by the American Industrial Hygiene Association (AIHA). The questions in the checklist are structured along Deming’s Plan-Do-Check-Act (PDCA) cycle as follows: OSH Policy (Plan), Planning (Plan), Implementation and operation (Do), Checking and corrective action (Check) and Management review (Act).

Upon completion of the ConSASS Audit, the scores and the supporting audit documents should be submitted through the WSH eServices system on the MOM website (http://www.mom.gov.sg).

# Developing Conceptual Framework of Intelligent Productivity and Safety System (IPASS)

The study followed the conceptual framework depicted in Figure 1. It considered key aspects of safety and productivity at the project level in order to develop IPASS in order to manage risk by controlling hazards. In occupational health and safety (OHS) management, risk is caused by the presence of hazards that may trigger the occurrence of incidents with harmful consequences such as personal injury or property/environmental damage. The probability of this negative occurrence is the risk associated with it (EHSToday, 2016). Hamidi, Omidvari and Meftahi (2012) also noted that there is an effect of the risk management system on safety and productivity indices.

*Figure 1. Conceptual framework of Intelligent Productivity and Safety System (IPASS)*

To method adopted to accomplish the objectives of the study (outlined earlier) consists of the steps presented in Figure 2.

*Figure 2. Research methodology*

## Literature Review (Step 1)

The first step in the development of IPASS was to review the various ways in which BIM has been explored to improve productivity and safety performance in the construction industry globally in general, and in Singapore in particular. This included an investigation of the potential of, benefits from, and challenges encountered in, BIM implementation in the industry. In accordance with the concepts of risk management, there is greatest scope for identifying and mitigating risks in the early stages of the project. Therefore, ideally most of the foreseeable risks should be ‘designed out’ during the planning and design stages, and the residual risks should be managed during the construction and subsequent phases (Zou et al, 2016). Gambatese et al (2008) stressed that as many risks as possible should be considered and dealt with at the design phase so there is a strong link between designing for construction safety and construction site fatalities. The Risk Analysis Process presents a typical analysis loop suggests that decision makers should establish the project context and an effective communication environment, make risks explicit, analyse them, take measures to control them, and review, record and report the results properly (Hamidi et al 2012).

## Review of Project Case Studies and Practices (Step 2)

In step 2, 18 in-depth, face-to-face, interviews were conducted with 30 representatives of 12 firms and institutions from January to December 2014. The objective of the interviews was to establish the baseline in terms of the Singapore construction industry’s practice of productivity and safety improvement, and the application of BIM. The interviews were intended to unearth the current issues and concerns with respect to productivity, safety and BIM.

## Questionnaire Design (Step 3)

Next, a questionnaire was designed. It sought to investigate issues including companies' policies and approaches with regard to productivity and safety, existing methods for measuring productivity and safety levels on projects, companies' experience with the relationship between productivity and safety and companies' knowledge and application of BIM.

## Data Collection and Analysis (Step 4)

In step 4, empirical data was collected through the questionnaire. The respondents of the questionnaire-based survey comprised main contractors and consultants. The target population for main contractors comprised companies that were registered with the BCA under registration heads CW01 (general building) and CW02 (civil engineering), with tendering limits ranging from the highest (A1) to the lowest (C3) of the classifications. A total of 383 contractors were identified. The consultants, consisting of architectural firms, structural engineering firms, mechanical and electrical (M&E) engineering firms, and quantity surveying firms were selected from the lists of members provided by the respective professional institutions in Singapore. A total of 454 consultants were selected. Hence, the total number of companies to which the invitation e-mails were sent out was 837. A total of 59 firms responded to the questionnaire-based survey.

After the completion of the field work, data analysis was undertaken to understand the industry’s views on safety and productivity, and the current stage of efforts towards productivity and safety improvement as well as BIM implementation in the industry. Many rounds of discussions with the Workplace Safety and Health (WSH) Institute of Ministry of Manpower (MOM) led to the structure of IPASS as illustrated in Table 2 and Figure 3.

*Table 2. Computation of productivity and safety scores*

*Figure 3. Computation of productivity and safety scores*

**Summary of Main Findings**

The details of the results of the interviews and questionnaire-based survey are reported elsewhere. The key points are presented in Table 3. They indicate that benefits and challenges of BIM. This formed the basis for the development of IPASS.

*Table 3. Key points of the results of the interviews and questionnaire-based survey*

## Integration of Productivity and Safety using BIM (Step 5)

Step 5 involved an integration of productivity and safety, utilising BIM as the platform for managing hazards in the risk management process. The aim of the proposed system (IPASS) is to determine the productivity index and safety index of a building using BIM, the buildable design concept and design for safety via ConSASS which adopts the risk management approach. The computation of the productivity score is based on buildability score, detailing the structural systems, wall systems and other buildable design features. The computation of buildability score follows the Code of Practice on Buildability, 2014 Edition (BCA, 2014). The Safety score is computed based on the hazards detected in the structural systems and wall systems, and the ConSASS assessment (Table 2 and Figure 3).

## Productivity Score

The BD Score of a project is made up of three parts: Structural System (maximum 45 points), Wall System (maximum 45 points) and Other Buildable Design Features (maximum 10 points). This allocation of points was based on manpower consumption (BCA, 2014). Bonus points are obtainable in each of the three parts for the use of productive technologies, such as mechanical connections for precast joints, self-compacting concrete, simple design, dry construction and mechanical, electrical & plumbing (MEP) systems, high impact productive and modern construction systems as well as the adoption of single integrated components and industry-wide standardisation of building components or design parameters. The maximum BD Score achievable for a project is capped at 100 points. The calculation of BD Score of a building follows the formula as depicted in Figure 4.

*Figure 4. Formula of calculation of BD Score of a building*

The BD Score for a particular structural system and prefabricated reinforcement is the product of the percentage of coverage of use and the corresponding labour saving index as shown in Table 2 (BCA, 2014). The BD Scores for the different structural systems adopted and the use of prefabricated reinforcement are then summed up and multiplied by the weight factor to arrive at the BD Score of the various structural systems and prefabricated reinforcement. The BD Score achievable for structural systems and prefabricated reinforcement is 45 points. Bonus points are given for the use of recommended precast joints from specified publications with the aim to improve the quality of precast design which will facilitate ease of precast production and installation. Bonus points are also given for the use of mechanical connections for precast joints, high strength concrete, self-compacting concrete and diaphragm wall.

The BD Score for a particular wall system is computed by multiplying the percentage wall length covered by the wall system and its corresponding labour saving index (BCA, 2014). The BD Scores for the different wall systems adopted are then summed up and multiplied by the weight factor to arrive at the BD Score of the various wall systems. Up to 5 direct points are awarded to designs that are simple to construct.

Under ‘Other Buildable Design Features’, the buildability of the design is examined at the detailed level (BCA, 2014). Buildable design features such as standard-sized columns, beams, windows and doors, grids and the usage of prefabricated or precast components are considered. The maximum BD Score that can be achieved in this section is 10 points.

Bonus points are given for the use of single integrated components such as prefabricated bathroom or toilet units, precast household shelters and precast external walls with cast-in windows, as well as industry-wide standardised building components and design parameters such as standard floor heights with standard precast staircases, door structural openings and so on. Designs that adopt dry construction such as the use of drywall for party wall and wet areas, and labour saving MEP systems such as flexible sprinkler dropper are also awarded bonus points. These bonus points should add up to a maximum of 20 points.

Although the maximum BD Score achievable under the 3 main parts of Structural System, Wall System and Other Buildable Design Features is 120 points, the BD Score of any design is capped at 100 points.

A Labour Saving Index (LSI) is a value given to a particular building system and also for the use of prefabricated reinforcement/cages in cast in-situ components (Table 4). The BCA developed the LSI firstly by identifying projects for each type of building system (BCA, 2014). Site productivity, measured in square metres per manday, relating to each building system, was analysed. Based on the relative differences in labour productivity, the LSI for each building system was derived. In certain instances, the LSI could be further lowered to discourage the use of labour intensive elements or components. A high index indicates that the design is more buildable and fewer site workers are needed.

*Table 4. Labour Saving Index (LSI)*

## Safety Score

Safety score is generated based on types of hazards and ConSASS score. A safety hazard library was developed based on the main contributors to fatal accidents in the construction industry and a series of discussions with the representatives from the WSH Institute which led to the list of hazards as shown in Figure 3.

The maximum score that can be achieved based on the prevention of hazards is 90. The maximum score that can be achieved through ConSASS assessment is 10. Further details on the calculation of scores are given in the next section.

## Development of IPASS (Step 6)

A group of researchers were using rule algorithm to develop construction safety ontology that enabled more effective inquiry of safety knowledge based on rules for job hazard analysis. They found that the links between construction safety management and information models are missing (Zhang et al., 2014; Zhang et al., 2015; Malekitabar et al., 2016; Zou et al., 2016). Already, numerous research works have explored the use of BIM to enhance safety performance since the DfS and BIM have been around for the past decade now but none of these studies had attempted to apply the integration of BIM, DfS, ConSASS, Control Measure and Hazards Identification to enhance safety performance on construction sites (refer to Table 5). Even the most recent studies by Zhang et al (2015a and 2015b), Malekitabar et al (2016), Golovina et al (2016) and Zou et al (2016) had also not attempted to apply the integration of five focus areas into one system (refer to Table 5).

*Table 5: Previous research on the application of BIM to enhance safety performance*

The proposed IPASS is able to identify hazards with the rule-checking capabilities. According to Zou et al (2016), the unidentified risks may lead to a superimposed effect and the possibilities of hazards will therefore increase. Thus, projects might be delayed due to stop-work orders; this would affect the activities on sites, leading to an adverse impact on productivity performance. IPASS has the capabilities to proactively identify hazards and mitigate risk during the Design Stage and this is an important feature as Carter and Smith (2006) highlighted that all risk management methods become ineffective if any risks could not be detected before they happen. IPASS is significantly easier to check (quality check capability) any mistakes and the rationality of a design in the 3D environment as the rich parametric information is linked to the objects (Eastman et al 2011). Besides the feature of IPASS to mitigate risk at location (by identifying risks virtually before construction), it has other features which help to mitigate risks by eliminating hazards as there are built-in safety measures/control rules to overcome the problems which are caused by various reasons such as deficiencies in the design, selection of the wrong material, and so on. Such a feature is essential for enhancing safety and productivity since studies conducted by Tam et al (2004) showed that hazards related to safety and productivity were observed frequently due to poor risk management.

As mentioned above, IPASS consists of two modules: productivity module and safety module. The two modules were developed with BIM as the integrating platform. All property information of the BIM model was defined by referring to the BIM guides of the BCA.

The productivity index of the productivity module was built by taking into account the BD score of the BCA. The productivity module consists of the structural system (maximum 45 points), wall system (maximum 45 points) and other buildable design features (maximum 10 points). The maximum productivity score achievable is 100 points.

The safety index of safety module was built by taking into account the types of hazards, control measures of hazards detected in the structural and wall systems, and ConSASS. The maximum safety score that can be achieved based on the prevention and control of hazards is 90 (maximum 45 points for the structural system and maximum 45 points for the wall system). ConSASS assessment is taken into consideration by giving the building a score for each band attained (from Band I to IV). The maximum score that can be achieved through ConSASS assessment is 10, which is when the building under assessment attains the highest band (Band IV). Hence, the maximum safety score achievable is 100 points.

## A summary of the mechanics of how the framework is achieved is now presented.

The type of information needed before the system worked well are: (i) the BIM model must be correctly modelled based on the prevailing rules and regulations, (ii) the BIM model must have the right level of details (LOD) [quality of BIM], and (iii) the hazard controls must be correctly considered (hazard check).

The proposed system is designed based on receiving a REVIT model as most of the companies in Singapore’s construction industry are using REVIT. The project team sought to test the system with ArchiCAD software. Thus, the students’ models were used for testing the capabilities of the proposed system for ArchiCAD. The validation results showed that the proposed system is able to work with ArchiCAD as well.

The detail in the model will be managed by the rules algorithms.The proposed system is a tool designed to help the construction industry to enhance productivity and safety performance on their building projects. However, it has to be acknowledged that it is only a tool, and the users can simply feed in erroneous data to pass the scoring thresholds but they would run the danger of putting the project at various levels of risks if accidents occur, or productivity is poor.

The hazards (Figure 3) had been identified in a series of meetings with industry and the authorities. However, the list of high level causes of accidents are quite standard issues. The contribution to knowledge is not the list itself, but the abilities of the system to identify the hazards, and analyze and quantify risk. Another contribution is the control features that provide warning signs to the users.

## Validation of the System (Step 7)

IPASS was validated by the following method:

1. Using the BIM models (Revit) of three actual building projects: (i) a project consisting of academic and training workshop blocks; (ii) a residential project; and (iii) a civic and retail project. The BIM models, were prepared by the main contractors. These versions were used instead of the designers’ models because, the designers’ models were incomplete. The BIM models produced by the Contractors had higher levels of details.

2. Using the BIM models of eight virtual projects (ArchiCAD) prepared by eight groups of students. (Outside the scope of the research study)

The validation process was performed by comparing the manual computation of productivity and safety scores with those generated by IPASS. An analysis was carried out to find out the causes of differences and propose the solutions. From the validation process, it can be concluded that for IPASS to work well, it is necessary for the models to be built well. The research team had to modify the BIM models it received based on additional information provided by the contractors, including tabulation of buildability score and as-built floor plans (only modifications within the scope of the research study were undertaken). This makes BIM quality assurance and the preparation of an accompanying IPASS Guide important. The validation process also showed that the proposed IPASS not only can determine the productivity and safety indices of Revit BIM Models but also that of ArchiCAD BIM Models.

It is significant in this research if REVIT or some other commercial software (such as ArchiCAD) is used as it validates and confirms the robustness of the proposed system; and it demonstrates the ‘openness’ of the system as the proposed system uses the Open BIM approach.

# Conclusion

The unbundling and analysis of the factors which influence project performance is important in order to address some of the endemic problems of the construction industry which hinder its progress towards excellence. The paper demonstrates that BIM can help stakeholders to consider productivity and safety at the earliest stages of the construction process, with the main aim of improving productivity and safety. It outlines a framework for integrating productivity and safety indices with BIM as the platform, resulting in IPASS.

IPASS is capable of pinpointing certain high-risk areas during the design stage, enabling hazard mitigation strategies to be applied. At the same time, productivity of the project, based on buildability score attained, could be monitored. This intelligent BIM-based system allows the users to identify and manage unsafe designs and the risks they might cause, while monitoring the buildability score attainable. Thus, it allows close monitoring of the safety and productivity improvement before the project, and as the project progresses.

Hence, IPASS can be used by construction project managers to plan site activities and safety programmes to focus on the higher-risk trades and prioritise hazard mitigation strategies and intervention methods to make effective resource allocation decisions.

The limitations of the study were mainly because the industry was still at the transition stage in implementing BIM. Firstly, BIM models obtained for validating the system contained only basic information on the buildings. Owing to the lack of detail, IPASS was not able to perform most of the checks that it was being built to check. Secondly, while ideally the same BIM models used for submission to the authorities could be inputted into IPASS for the purpose of productivity and safety monitoring, some manual effort may still be required so that IPASS could be used to its maximum capability. Depending on the level of detail of the BIM model, the manual effort may include inputting the details of building systems and safety measures as required by IPASS. As BIM submission for projects has been made mandatory and BCA is encouraging participants from different disciplines to collaborate in a seamless manner, the quality of the BIM models will be increasingly more important, and users should be able to utilise IPASS to its potential.

Though there are limited number of implications for the practitioners at this transition stage in implementing BIM nonetheless this could be proffered to demonstrate how the paper bridges the gap between theory and practice; and its subsequent impact on society.

The main concepts already exist in the scientific literature but these concepts did not incorporate BIM, DfS, ConSASS, Control Measures and Hazards Identification into one system for enhancement of safety and productivity performance using the Open BIM Approach for Singapore. The significant contribution to knowledge is the further demonstration of the linkage between productivity and safety performance. Among the practical contributions is that the practitioners can use the proposed system to monitor their safety and productivity performances at Design Stage and Construction Stage. In addition, the reports generated by the proposed system can be used for making the mandatory submissions to the authorities. Normally, the practitioners have to calculate the buildability-score manually; this was time consuming, especially for buildings with complex designs. The reports contain detailed data which explain reasons for low safety and productivity scores, and suggest possible actions. The proposed system is viewed by Singapore authorities to be a robust open system.

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