Challenges Associated with Implementing BIM-Enabled Code-Checking Systems within the Design Process

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Statement for originality

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TERMINOLOGY

accredited certifier	those who are accredited by ABCB to deal with certifying building designs for compliance, including council and private certifiers.
certifying authority	a local council, an accredited private certifier and the Minister for Planning & Infrastructure.
stakeholder	those who are involved with the entire building process of a project, working as a team, including project managers, architects, engineers, contractors, consultants, clients, and other disciplines.
participant	those who were interviewed in the evaluation process in this study, including accredited certifiers and architects.

ACRONYMS

2D	Two-Dimensional
3D	Three-Dimensional
ABCB	Australian Building Codes Board
BCA	Building Code of Australia
BIM	Building Information Modelling
BIM-CCS	BIM-enabled Code-checking System
BP Act	Building Professionals Act 2005
BPB	Building Professional Board
CAD	Computer-aided Design
CC	Construction Certification
CDC	Complying Development Certificate
CORENET	Construction and Real Estate NETwork
DA	Development Application
DL	Dialog Language
DTS	Deemed-to-Satisfy
EP&A Act	The Environmental Planning and Assessment Act 1979
FRL	Fire-resistance Level
IAI	The International Alliance for Interoperability
IFC	Industry Foundation Classes
NBI	The National BIM Initiative
NCC	The National Construction Code Series
NSW	The state of New South Wales
RASE	Requirement, Applicability, Selection and Exception

ABSTRACT

This study has involved the specification and development of a Building Information Modelling (BIM) enabled code-checking system to check building designs for compliance against the Building Code of Australia (BCA). In Australia, building designs must comply with the BCA before construction works commence. At present accredited certifiers manually assess two-dimensional design drawings against each clause of the BCA. However, these manual activities have been shown to be time-consuming and inconsistently executed, and have informed two research gaps identified for this study. Firstly, design modifications are sometimes not noted on two-dimensional drawings, particularly when these are updated. This may fragment the information that stakeholders share, resulting in drawings and designs that do not match assessment results. Stakeholders then need to spend additional time repeating certification activities. Secondly, the BCA is a set of continuously changing and increasingly complex regulations. Code clauses may be cross-referenced and contain open-ended conditions. This could lead different certifiers to have different interpretations of BCA codes. Certifiers therefore need to rely on their experience to determine whether or not building designs comply, resulting in inconsistent assessment results. Where building designs do not comply, schedule delays and budget overruns ensue.

BIM represents a synergy between technologies, processes and policies. It provides a three-dimensional platform that stakeholders can use to collaborate and coordinate their designs throughout the entire design process. BIM supports software vendors to develop extensions to strengthen its capabilities. Many BIM extensions enable complex calculations and analyses to be conducted accurately and efficiently. This supports the research aim of incorporating a BIM-enabled code-checking system (BIM-CCS) into the design process. Several existing code-checking systems were reviewed. Most of them were research projects and few have been successfully implemented. Knowledge from these contributed to this study of developing a BIM-CCS specific to the Australian context. A BIM-CCS, called *Ignis*, has been incorporated into *Autodesk® Revit®*2014. It is designed to assess BIM models of commercial buildings (Class 5 to Class 9 buildings) against Section C Fire Resistance codes of the BCA.

This study has applied a Design Science methodology to developing *Ignis*. Within the development process, new knowledge has been created through the design of innovative artefacts, and effective results produced for users when *Ignis* is executed. Design Science research comprises five sequential procedures: awareness of problems, suggestions, development, evaluations and conclusions. In addition, Design Science

methodology emphasizes an iterative process of development, evaluation and further suggestions that enable artefacts to be refined. Semantic analysis methods were used to interpret Section C Fire Resistance codes of the BCA for designing code-checking rules. Challenges identified during this stage stemmed from either a lack of information provided by BIM models or the need for further calculations. Proposed solutions to these challenges were then developed. Some challenges were overcome by additional activities, while others needed regulatory content and BIM information to be aligned and therefore needed related parties to work collaboratively.

Three sequential evaluation activities were then conducted (preliminary, first and second evaluations). Demonstrations and interviews were adopted for each evaluation activity. In the preliminary evaluation, an accredited certifier was invited to assess the efficacy of *Ignis* against four topics: structure, rules, reports and interface. Each topic contained specific evaluation criteria such as functionality, efficacy and usability. The preliminary evaluation results verified the efficacy of the *Ignis* prototype, while some information, such as floor area for each storey, was suggested to be added to reports. A first revision *Ignis* was then used in the first evaluation. Six accredited certifiers were randomly selected to assess the efficacy of *Ignis* (1st revision). They acknowledged that *Ignis* (1st revision) successfully checked the fire resistance rules of the BCA. However, this exercise highlighted the fact that different accredited certifiers interpreted BCA clauses in different ways. This is due to a fact that several BCA clauses are open to interpretation. Accredited certifiers observed that the reports were not well-designed and were inconvenient to refer to because they were separated into too many pages. This led to redesign the *Ignis* (1st revision) interface as a second revision. The *Ignis* (2nd revision) was then assessed by a group of architects. They endorsed the need for *Ignis*-like systems to help assess whether their designs complied with the building regulations during the design process. In addition, they also noted that *Ignis* (2nd revision) was able to inform stakeholders how to identify building elements and/or solutions during the design process. Furthermore, they noted these actions could change the ways in which stakeholders engaged with the BCA during their design activities.

Overall, this study has demonstrated the potential and opportunities for the development of BIM-CCSs for Australia. The evaluation results have demonstrated two significant outcomes that address the identified research gaps. Firstly, *Ignis* can assess building designs for compliance in an efficient manner and streamline design and certification processes. Secondly, where BCA clauses are explicitly specified, *Ignis* can produce consistent assessment results of building designs. The development of a fully functional BIM-CCS will require building-related professionals to participate in refining the BCA to harness the capacity of this new technology. The contribution of this study is to establish the knowledge of designing *Ignis* as an artefact outcome of Design Science research.

1 INTRODUCTION

This thesis explores the Australian regulatory framework and certification system, design processes and building technological developments, and emphasizes the significance of code compliance works for building designs using computerized technology during the design process.

Building designs must be assessed for compliance with building regulations prior to construction work starting. These designs should be checked for code compliance before being lodged with certifying authorities. However, project stakeholders, such as architects, usually lack sufficient knowledge of building regulations to assess their building designs (Fischer, J. and Guy 2009, Hunt and Raman 2000). Moreover, certifying authorities and/or consultants are not involved in the design process or can only participate in late design stages (American Institute of Architects (AIA) 2007). These factors make it difficult for compliant building designs to be generated during the design process. If building designs do not comply, labour costs, contract duration and budgets may increase. This highlights the need for incorporating code compliance activities into the design process. Ralph (2001) supports this assumption and states

> 'Code compliance review must begin early in a project so that any conflicts with applicable codes can be ironed out before they become difficult or expensive to correct. Likewise, it is best to get any specialty consultants required for the project on board early so there are no surprises later in the process.' (2001: 53)

Technical progress in building designs has made it possible to mitigate and/or overcome these challenges (Rogers 2012). Building technologies provide opportunities to develop a range of extensions that help project stakeholders deal with diverse design works (Hu et al. 2008, Olofsson et al. 2008, Lijun and Chua 2011). Numerous industry-related and academic sources are at one in promoting the benefits of Building Information Modelling (BIM) (Hurst 2012, Pitt 2011, Fitzpatrick 2012). BIM has emerged as a technical evolution in the ways project stakeholders design, construct and manage buildings (Pollock 2010). Additionally, many BIM-based extensions have been created for specific design works (e.g. clash detections and schedule management) (Kim, H. et al. 2013, Nisbet, Nick and Dinesen 2010, Seo et al. 2012). This supports incorporating BIM-enabled code-checking system (BIM-CCS) technologies into the design process to address to the research problems (identified in section 1.2 at page 3) for this study.

1.1 Research context

Completion of a building design may be attributed to a series of collaborative design activities that require the engagement of multiple disciplines. This may begin with the preparation of conceptual designs, through to schematic designs and design development, and finally document design drawings for certification works (American Institute of Architects (AIA) 2007, RIBA 2012). At present, building designs in Australia must comply with the Building Code of Australia (BCA) (Australian Building Codes Board 2013) before any construction work begins. There are three key issues that affect the performance of the certification process: (1) coordination of documentation, (2) stakeholders' knowledge of the BCA, and (3) interpretations of the BCA codes.

Throughout the entire design process, a large number of two-dimensional (2D) drawings are created in paper-based format by multiple disciplines at different design stages (Wikforss and Löfgren 2007). In addition to exchanging information between project stakeholders, paper-based 2D drawings are typically used to represent information for certifying activities. When certifying authorities approve building designs and issue certificates, construction works are then permitted to commence (Building Professionals Board 2011).

However, documenting design drawings is a manual process that may result in fragmented information and repetitions of work among stakeholders when these documents are not well-organized (John et al. 1997). For example, design modifications may not be recorded on 2D drawings, particularly when these are updated. This may result in fragmented information between project stakeholders and accredited certifiers. If drawings do not match assessment results, stakeholders and certifiers then need to spend additional time repeating certification activities.

In addition, building designs that can be successfully certified for approval either need stakeholders with a strong awareness of the BCA or consultant's assistance in checking for code compliance. However, in certain cases, stakeholders may be reluctant to explore building regulations during the design process. Some stakeholders, particularly designers, view the task of checking their designs against the requirements of building regulations as burdensome and impeding their creativity (Fischer, J. and Guy 2009, Hunt and Raman 2000). Furthermore, few construction projects engage code checking consultants in the design process (American Institute of Architects (AIA) 2007).

Finally, the BCA is a set of continuously changing and increasingly complex regulations (Tan et al. 2010, Greenwood et al. 2010). Numerous code clauses are constituted from cross-references and open-ended conditions with the result that accredited certifiers have been known to interpret BCA codes in an inconsistent manner (Fischer, J. and Guy 2009, Montoya 2013). Accredited certifiers therefore need to rely on their experience to determine whether building designs comply or not (Nawari 2012b). These anomalies may lead to inconsistent assessment results. Where building designs do not comply, schedule delays and cost overruns are likely to occur (Plume and Mitchell 2007).

1.2 Research problems

Issues in assessing building designs for compliance have been explored in the previous section. The research problems identified in this study are:

- Poor coordination of design drawings between project stakeholders and certifying authorities can result in repetition certification work.
- Stakeholders' lack of knowledge of the BCA impedes them from obtaining approval of their building designs.
- Building codes are open to different interpretations and may result in inconsistent certification outcomes.

1.3 BIM-CCS as a strategic tool

BIM represents an integrated repository including policies, processes and technologies, which supports project data (created from multiple disciplines) to be merged in digital formats (Babič et al. 2010, Grilo and Jardim-Goncalves 2010, Succar 2009). This may alleviate many of the problems associated with paper-based documents. BIM also provides a platform that allows computer programmers to develop extensions to strengthen BIM capacities. Many BIM extensions, such as clash detection, cost estimation and schedule arrangements, have been developed and implemented in the construction industry (Kim, H. et al. 2013, Nisbet, Nick and Dinesen 2010, Seo et al. 2012). These BIM extensions highlight the potential for the development of BIM-CCS. The BIM-CCS may assist in assessing building designs for compliance against building regulations (Abrantes 2010, Jeong, J. and Lee, G. 2010, Greenwood et al. 2010).

Preventing variations from occurring in the first place is preferable to taking remedial action at a later date. Many studies have demonstrated that the earlier in the design stage in which the project stakeholders collaborate, the lower risks and costs (Azhar 2011, Kiviniemi 2011, Smyth and Pryke 2008). The MacLeamy Curve (Figure 1.1) illustrates a shift in time distribution between BIM adoption and traditional design (Holzer 2011). When project stakeholders use BIM from an early stage, they spend less time coordinating drawings in the construction documentation stage, thereby reducing the risks and costs of inconsistent certification work and variations of construction work (Jeong, J. and Lee, G. 2010, Plume and Mitchell 2007).

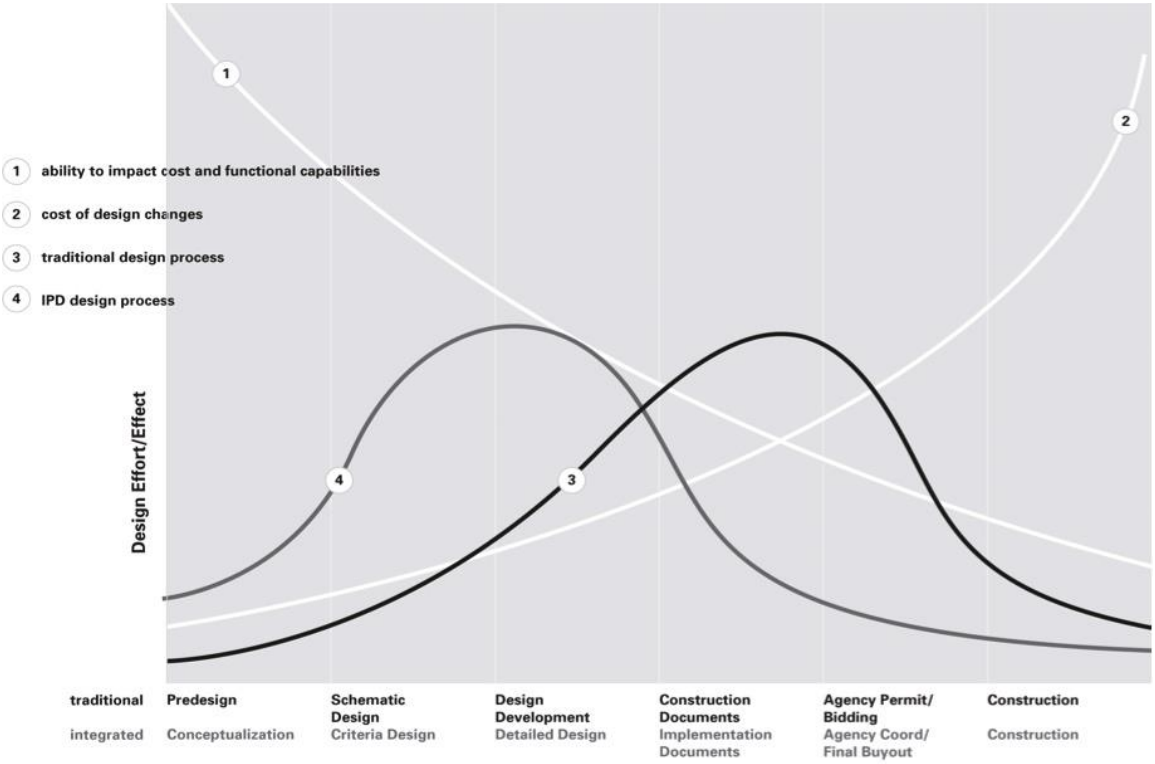


Figure 1.1 The MacLeamy curve for BIM resource timing

Source: (Holzer 2011: 470)

This is underpinned by the observation that BIM and its extensions enable rigorous and complex analyses and calculations to be conducted in an efficient and accurate manner, thereby minimizing and/or eliminating errors and omissions during the design process (Rogers 2012). In addition to efficiency and accuracy, code-checking systems using BIM should be able to assess and determine whether building designs comply or not (Ding et al. 2004, 2006). Project stakeholders can then address the design issues identified during the design process. It is likely that this will reduce the risk of building designs being judged as non-compliant and failing the certification assessment (Ralph 2001).

Thus far there are few BIM-CCSs that enable building designs to be assessed for compliance with building regulations, particularly within the context of the Australian construction industry. Among the developed BIM-CCSs, the Construction and Real Estate NETwork (CORENET) project, developed by Singaporean governing bodies, represents a pioneering start in BIM-CCS research domain (Khemlani 2011). Additional significant examples include Statsbygg (Norway), ICC (USA) and DesignCheck (Australia) (Eastman, C. et al. 2009, Greenwood et al. 2010). These BIM-CCS projects and five additional research-based examples are further discussed in section 3.6 (at page 44). Although few have been implemented in practice, these BIM-CCSs provide valuable references for this study.

Of particular relevance to this study is DesignCheck. It was developed specifically to cater for the requirements of disabled people against the Australian Standard 1428.1 (Australian Building Codes Board 2013: 48–49). Despite being launched in 2005, little evidence has been found of DesignCheck being used in industrial practices. However, the DesignCheck study confirms opportunities to develop a BIM-CCS to assess building designs against the BCA.

BIM technology has been shown to improve poorly coordinated documentation. In addition, BIM technologies can be augmented through many extensions. These extensions can perform complex analyses and calculations consistently and accurately and thereby enable design problems to be addressed during the design process. These all support the development of a BIM-CCS to address to the identified research problems.

1.4 Research scope

Building design compliance processes in Australia vary between states. The requirements of each state are different due to several considerations including climate and geographical conditions (Australian Building Codes Board 2013). In this research, the researcher has focused on the domain of building design compliance in the State of New South Wales (NSW), Australia. NSW has been chosen as the research domain because it represents the largest proportion of the Australian economy compared to other states. The NSW economy was valued at $487.6 billion in 2013-14, representing 30.8% of total GDP of Australia (The Australian Bureau of Statistics 2014).

Within the BCA, building designs are classified into ten groups (Table 1.1), which have disparate requirements. Moreover, some building classes can be divided into sub-classes such as Class 1, 7, 9 and 10. Excluding Class 1 and 10, the building classifications can be categorized in two groups: residential and commercial buildings. Residential buildings comprise Class 1 to 4 while commercials comprise the rest.

Residential building designs can be approved to commence construction work through an approach called a ‘Complying Development Certificate (CDC)’ (NSW department of Planning and Environment 2015). CDC is a one-stage approval approach that allows residential designs to be approved in a timely manner. As such, these approvals can be issued based on a statement of intent by certifying authorities without the need for detailed drawings. However, a CDC based on insufficient design information can result in variations of construction works. This research therefore excludes such classes of residential buildings and focuses on checking buildings in commercial usage that belong to class 5, 6, 7, 8 and 9.

Table 1.1 Classification Summary of Buildings and Structures defined in the Building Code of Australia

Class		**Definitions**
Class 1	Class 1a	A single dwelling being a detached house, or one or more attached dwellings, each being a building, separated by a fire-resisting wall, including a row house, terrace house, town house or villa unit.
	Class 1b	A boarding house, guest house, hostel or the like with a total area of all floors not exceeding 300m2, and where not more than 12 reside, and is not located above or below another dwelling or another Class of building other than a private garage.
Class 2	A building containing 2 or more sole-occupancy units each being a separate dwelling.	
Class 3	A residential building, other than a Class 1 or 2 building, which is a common place of long term or transient living for a number of unrelated persons. Example: boarding-house, hostel, backpackers accommodation or residential part of a hotel, motel, school or detention centre.	
Class 4	A dwelling in a building that is Class 5, 6, 7, 8 or 9 if it is the only dwelling in the building.	
Class 5	An office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.	
Class 6	A shop or other building for the sale of goods by retail or the supply of services direct to the public. Example: café, restaurant, kiosk, hairdressers, showroom or service station.	
Class 7	Class 7a	A building which is a car park.
	Class 7b	A building which is for storage or display of goods or produce for sale by wholesale.
Class 8	A laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing, or cleaning of goods or produce is carried on for trade, sale or gain.	
Class 9	A building of a public nature -	
	Class 9a	A health care building, including those parts of the building set aside as a laboratory.
	Class 9b	An assembly building, including a trade workshop, laboratory or the like, in a primary or secondary school, but excluding any other parts of the building that are of another class.
	Class 9c	An aged care building.
Class 10	A non-habitable building or structure -	
	Class 10a	A private garage, carport, shed or the like.
	Class 10b	A structure being a fence, mast, antenna, retaining or free standing wall, swimming pool or the like.

Source: (Australian Building Codes Board 2013: 42)

1.5 Limitations of the study

One of the major limitations of this study results from the fact that the BCA is presented as a large and complex semantic structure. A considerable amount of time and effort is needed for interpretive analysis (refer to section 4.5.1 at page 74). It was therefore necessary to choose an appropriate section of the BCA to study. Interpreting the entire BCA and converting it into a rule-based database (one component of the BIM-CCS) is outside the scope of this study. The BCA can be categorized into several main topics (e.g. Fire Resistance and Egress), and separated by each state in Australia (e.g. New South Wales and Queensland). Many studies have indicated the importance of fire resistance, which is one of the main areas that certifying authorities are most concerned with (Delis, E. A. and Delis, A. 1995, Stollard and Abrahams 1999, Jeong, J. and Lee, G. 2010). The scope of this study is confined to the building regulations for New South Wales and focuses on the building codes in Section C Fire Resistance codes.

1.6 Aim and objectives

The aim of this research is to develop a proof of concept BIM-CCS that enables building designs to be checked for compliance against the BCA. This BIM-CCS has been named '*Ignis*' to incorporate the concept of 'fire' from Latin. The following three objectives have been developed to serve the research aims:

- To develop a structure for *Ignis* specific to Section C Fire Resistance of the BCA for commercial buildings.
- To enable an *Ignis* prototype to perform effective code-checking activities.
- To investigate the manner in which project stakeholders use *Ignis* to facilitate design activities during the design process.

1.7 Significance of the study

This study developed *Ignis* specific to commercial buildings and fire resistance codes within the context of NSW, Australia. Incorporating *Ignis* into the design process can assist project stakeholders to assess whether their designs comply with building codes in a consistent manner. Project stakeholders can revise their designs in accordance with the assessment results and then present their revised designs for compliance checking. This reduces the requirement for certification authorities to identify non-compliance instances that occurred in the designs.

The outcome of this study is the creation of *Ignis*. It can read BIM model parameters directly for code-checking activities. This alleviates the challenges that result from the poorly coordinated documentation works. In addition, interpreting code clauses using semantic analyses methods enables the *Ignis* rules to be designed in a systematic manner. This makes it possible to assess building designs consistently. Moreover, *Ignis* enables project stakeholders to revise their designs in accordance with the assessment results. This will result in building designs complying with the regulative requirements once submitted to certifying authorities. This study demonstrates that *Ignis* can be designed to establish a framework for development and evaluation. This can be used for the development of BIM-CCS related studies in the future.

1.8 Structure of this thesis

The structure of this thesis is illustrated in Figure 1.2 and consists of the following chapters:

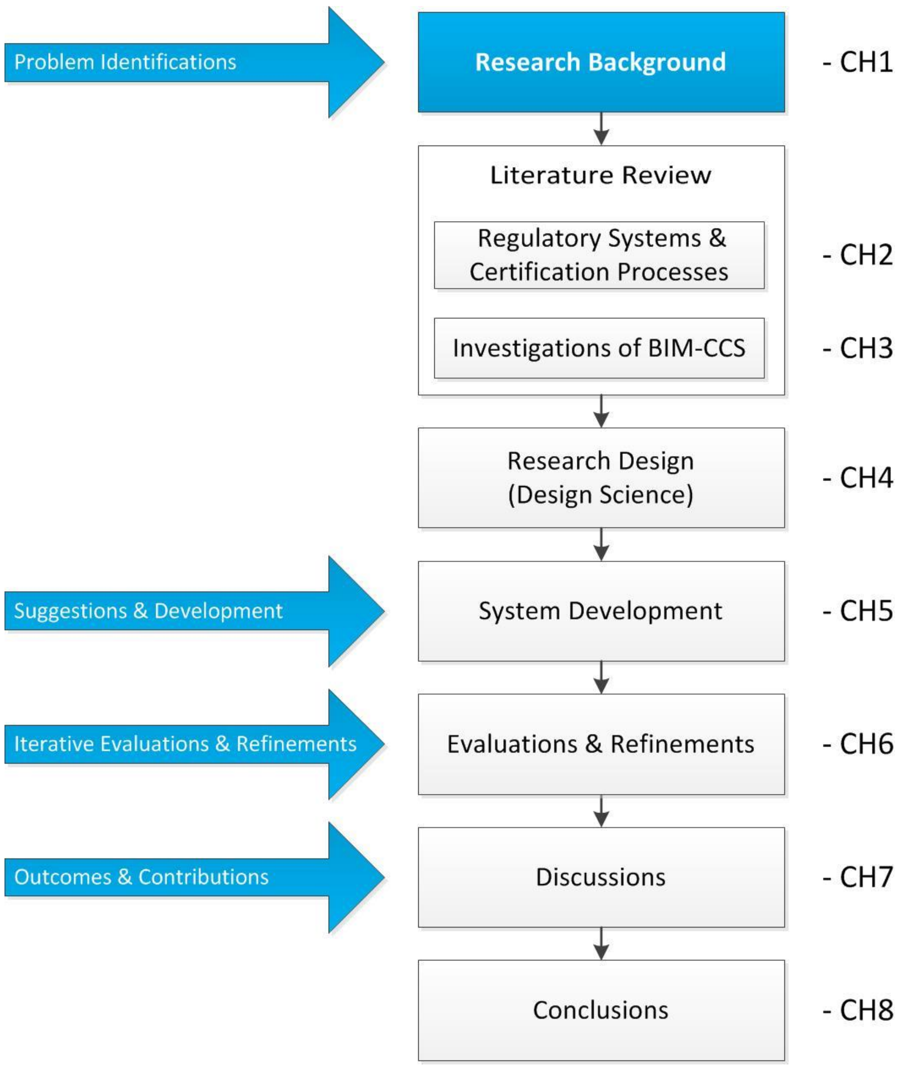


Figure 1.2 Structure of thesis

Chapter 2 reviews the current Australian building industry, as well as the building regulation and certification system for NSW. It firstly explores the contributions of the Australian building industry and how design compliance work is performed between stakeholders. This chapter also investigates the regulatory framework and certification processes. The hierarchical regulations for building designs are introduced. The building classifications and the fire resistance codes are also discussed in this chapter. The chapter concludes by identifying the *key issues* that emerged from the foregoing reviews and present *questions* that arose from the identified *key issues*.

Chapter 3 firstly explores the BIM technologies from various perspectives. This includes BIM definitions and characteristics, as well as how BIM affects design processes. Several BIM software packages are investigated and compared. This is followed by a review of BIM-CCS studies. Four rule engines used for developing code-checking rules are explored. Nine developed BIM-CCSs are then investigated, focusing on how they design rules and how BIM data informs the rules. A comparison between these BIM-CCSs is then provided. The chapter concludes by identifying the *key issues* that emerged from the foregoing reviews and present *questions* that arose from the identified *key issues*.

Chapter 4 describes the research design and methodology used in this study. It explores the nature of the questions raised in the Chapter 2 and 3 and presents approaches to achieve the research objectives. This study adopts a Design Science methodology to develop *Ignis*. Within Design Science methodology, methods to develop and evaluate the BIM-CCS can vary. This study firstly explores the semantic analysis methods of deconstructing building code clauses to inform code-checking rule designs. Evaluation methods are then discussed to enable participants to assess the BIM-CCS against the evaluation criteria. The evaluation criteria are set from relevant studies developed using Design Science methodology. These evaluation criteria can be categorized into four topics: system structures, code-checking rules, report information and system interfaces.

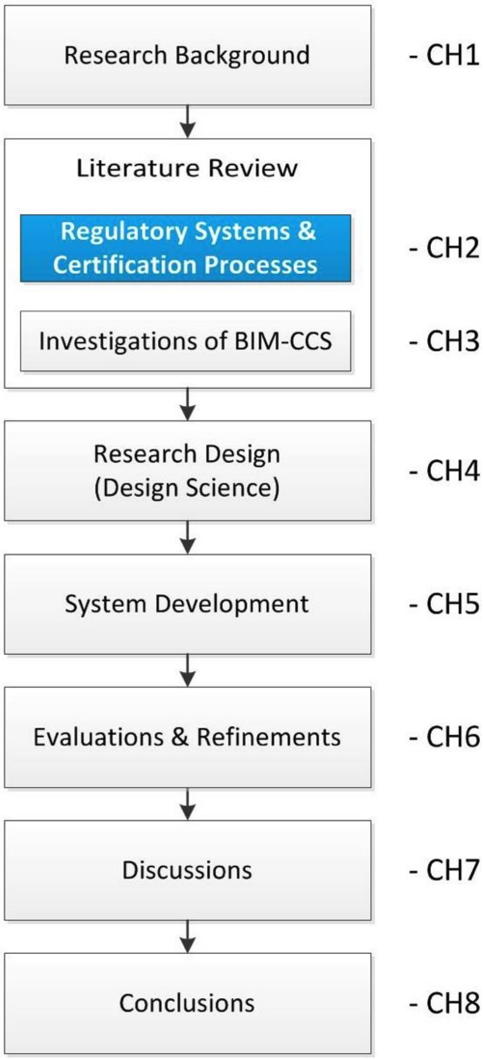
Chapter 5 outlines the ways *Ignis* was created. This chapter firstly illustrates and discusses the BIM-CCS structure. This clarifies the main components required to create *Ignis*. It then discusses the ways of interpreting building codes to inform the rule designs. Several examples and challenges are explored. This is followed by transferring assessment results into textual and visualized reports. Several practical reports are used as references to format the reports. Lastly, the system interfaces are introduced and explored.

Chapter 6 describes the various evaluation processes used for the BIM-CCS. It begins with an introduction of evaluation methods. These methods are used to enable participants to understand how code-checking rules operate and how assessment results are presented. The entire evaluation process comprises three stages including the preliminary evaluation, the first primary evaluation and the second primary evaluation. For the preliminary and first primary evaluations, one and six accredited certifiers were invited separately to assess the BIM-CCS. The second primary evaluation was held with a group of fifteen architects and two individual architects. In each stage, the participants assessed the BIM-CCS against the four topics described in Chapter 4. Their feedback was analysed relative to the evaluation criteria for each topic.

Chapter 7 provides further discussion about the entire BIM-CCS development process. The evaluation results from the previous chapter provide the foundations that underpin these discussions. The identified and potential capacities of the BIM-CCS are firstly discussed in the context of how they have enabled the research problems to be addressed. This is followed by a discussion about the multiple challenges and the additional efforts required of multiple disciplines. Lastly, the outcomes of this study are discussed in accordance with Design Science methodology frameworks.

Chapter 8 brings all the issues and findings covered in the preceding chapters to a conclusion. It draws on the discussions in Chapter 7 and aligns them with the objectives, aims and problems of this study. Finally, several recommendations for the future developments of BIM-CCSs are provided.

2 THE AUSTRALIAN CONSTRUCTION INDUSTRY & REGULATORY SYSTEM



2.1 Introduction

This chapter explores the characteristics of the Australian construction industry. It begins by reviewing the extent to which the construction industry contributes to the Australian economy. The notorious reputation of the construction industry is then discussed with respect to the waste of time, labour and expense that occurs in many construction projects. This waste is generally the result of complex and entwined issues. One that is pertinent to this study relates to the manner in which designs are assessed for compliance against building regulations. This chapter introduces the regulatory framework and certification system currently operative in NSW, Australia, followed by an overview of the Building Code of Australia (BCA) with specific reference to Fire Resistance codes. Finally, several key issues and research questions are identified.

2.2 Economic contribution of the construction industry

The Australian Bureau of Statistics identifies the construction industry as the third largest industry, contributing 8.3% to the Gross Value Added (GVA) for the Australian economy for the period 2012-13 (The Australian Bureau of Statistics 2014). In the same period, the construction industry workforce has increased employment to 1,047,000. The construction industry, as the second largest industry contributes 9.9% of total selected industries employment (e.g. mining and manufacturing). These statistics highlight the considerable influence of the construction industry on economic growth in Australia.

Figure 2.1 illustrates economic contributions between 2012 and 2013 against each state (The Australian Bureau of Statistics 2014). It shows the NSW having the highest economic contributions compared to other states. Within Australia, NSW provides employment at 32.5%, wages and salaries at 32.7%, as well as sales and service income at 30.7%.

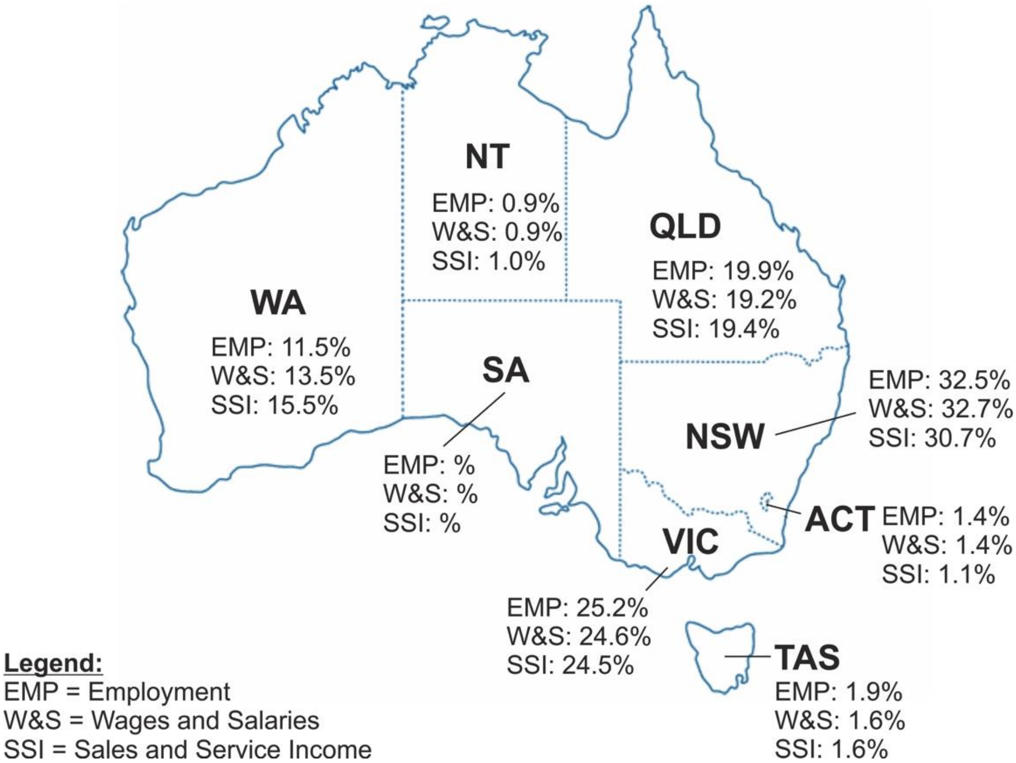


Figure 2.1 State / Territory contribution to all industries between 2012 and 2013

Source: (The Australian Bureau of Statistics 2014)

NSW at present has the largest number of new building construction projects. There were 34,700 new residential buildings approved in Sydney in 2013, compared with a low of 16,200 in 2009. The NSW employment market is also relatively strong. The unemployment rate within the NSW is half a percentage lower than the national average (Matt 2014). The growth in NSW buildings is underpinned by the large amount of new building activities and low unemployment rates. This can be attributed to the state's mature and developed construction business environment and justifies the focus of this study being on NSW.

2.3 Design compliance in the construction industry

Notwithstanding the substantial contribution of the construction industry to the Australian economy, this sector is generally not seen in a positive light. For example, 'the Australian construction sector operates in an institutional context that is highly cluttered (Hampson and Manley 2001: 34).' This is echoed by Loosemore (2012) who states 'the building and construction industry is complex, cluttered, fragmented and characterized by a broad range of disparate bodies with different and often conflicting interests and agendas (2012: 1).'

The construction industry has suffered from a poor reputation due to fragmentation and separation. This may lead to reduced productivity and performance which is evidenced by repetition of work, poor coordination of documents, variations to construction works, and risks on design compliance (Lingard and Francis 2004, Shen and Walker 2001, Whittington et al. 1992, Yeomans 2005). These issues may result in conflict between disciplines and relegate clients' requirements to a lower priority (Gray and Hughes 2001, Smith, J. and Jaggar 2007).

These complex issues are entwined and influenced by culture, process and policy (Smith, J. and Jaggar 2007). The focus of this study is to explore the manner in which designs of construction projects are assessed for compliance against the requirements of building regulations. The certification process (discussed in section 2.4.2, page 17) for building designs is performed sequentially. Certifying authorities need to issue certificates to developers before construction is allowed to start. If building designs do not comply at one stage, they are not permitted to commence next stage. Thus, in many cases, additional expenses for labour, schedule delays and budget overruns may ensue (Jeong, J. and Lee, G. 2010, Plume and Mitchell 2007).

Responsibility for ensuring that designs comply with relevant regulations is generally relegated to contractors and subcontractors (Cole 2002). This may be due to the fact that project teams are unfamiliar with the multitude of complex requirements of the BCA (Fischer, J. and Guy 2009, Imrie 2007). Many stakeholders experience difficulties assessing whether or not their designs comply with the requirements of the BCA during the design process. Moreover, design compliance-related disciplines are generally not involved in early design stages and issues may occur at a later design stage (e.g. certification process or construction stage) (American Institute of Architects (AIA) 2007, Faulconbridge 2009). However, many studies agree that engaging multiple disciplines during early design can effectively reduce risks and design variations later on (Becerik 2004, Kiviniemi 2011).

Apart from project teams, certifying and legislative authorities may interpret the BCA regulations in inconsistent ways (Fischer, J. and Guy 2009, Nawari 2012b). Moreover, the BCA allows for alternative solutions to be proposed and approved. Assessing these proposals relies on the experiences of certifying authorities. The Master Builders Australia argues that:

> '…the Commonwealth Government and in particular those government officials who administer the National Code, have no understanding of the reasons for the Code, nor how different the conduct prescribed by, particularly, the Implementation Guidelines, is, from the usual experience on building sites around Australia, and thus the additional expense, and loss of time, caused to those (particularly head contractors) which seek to ensure that the behaviour set out in the Implementation Guidelines obtains on building sites.' (Cole 2002: 75)

In Australia, few tools have been developed to help stakeholders assess building designs before submitting design proposals to certifying authorities. Ideally such tools need to facilitate assessment activities in a consistent manner during the design process. Many studies have explored the development of design compliance tools to facilitate stakeholders assess their designs (Abrantes 2010, Delis, E. A. and Delis, A. 1995, Ding et al. 2006, Eastman, C. et al. 2009, Jeong, J. and Lee, G. 2010, 2010, Khemlani 2011). The tools that are currently developed to assess compliance of building designs against building regulations are reviewed in section 3.6 of Chapter 3 (at page 44).

2.4 Regulatory Framework and Certification System

In Australia, building regulations in all states and territories set legal requirements for the minimum standard for building-related works, although some provisions vary between states and/or territories. This is to ensure the health and safety of people in and around buildings. Building regulation and certification is a significant component of the NSW planning system where accredited certifying authorities engage in assessing buildings for compliance. In Australia, building designs are assessed for compliance with building regulations from the design through to the construction and for the life of a building. The certification process at present is performed manually by certifying authorities (Building Professionals Board 2011, Environmental Planning and Assessment Act 1979 1980). Approvals and certificates are needed to progress most building projects to the completion stage. However, as mentioned above, building regulation and certification is criticized for being complex and fragmented in NSW (Bukowski and Babrauskas 1994, Montoya 2013). This section provides an overview of the building regulatory framework and certification system, followed by an examination of the BCA and the requirements for developments specific to NSW.

2.4.1 Building regulatory framework

The NSW building regulatory framework contains multiple acts (Table 2.1). The ways to apply the provisions of the Act are dictated by relevant legislated regulations, rules, and codes. The Environmental Planning and Assessment Act (EP&A Act) 1979 and the Building Professionals Act 2005 (BP Act) take precedence over the others. The EP&A Act and BP Act provide the statutory framework for the building regulation and certification systems. The Building Professional Board (BPB), NSW Fair Trading and the Division of Local Government are the three main authorities that administer this legislation in NSW.

Table 2.1 The NSW building regulatory framework

Legislation	Administrative Agency	Responsible Minister
Environment Planning & Assessment Act 1979	Building Professionals Board	Minister for Planning and Environment
Building Professionals Act 2005	Building Professionals Board	Minister for Planning and Environment
Consumer, Trader & Tenancy Tribunal Act 2001	Consumer, Trader & Tenancy Tribunal	Minister for Fair Trading and Minister for Finance and Services
Fair Trading Act 1987	NSW Fair Trading	Minister for Fair Trading and Minister for Finance and Services
Home Building Act 1989	NSW Fair Trading (Home Building Service)	Minister for Fair Trading and Minister for Finance and Services
HomeFund Commissioner Act 1993	NSW Fair Trading	Minister for Fair Trading and Minister for Finance and Services
Local Government Act 1993	Division of Local Government	Minister for Local Government
Work Health and Safety Act 2011	WorkCover NSW	Minister for Finance and Services
Swimming Pools Act 1992	Division of Local Government	Minister for Local Government

Adapted from: (Local Government Association of NSW 2012)

The EP&A Act sets out the responsibilities for certifying authorities and principal certifying authorities. It requires certifying authorities to consider the impacts on both the natural and the built environments, the community where the proposed development is located as well as any land use change. Certifying authorities can be a local council, the Minister for Planning & Infrastructure or accredited private certifiers (These are certifiers who are registered and accredited by the NSW Building Professionals Board to provide building approvals, certification and consultation services to clients throughout all areas of NSW). They are allowed to issue three kinds of certificates: Complying Development Certificates; Construction Certificates; and Compliance Certificates (Building Professionals Board 2011). Certifying authorities can also be appointed as "principal certifying authorities" to issue Occupation Certificates or Subdivision Certificates for building or subdivision works. The function of each certificate is explained in Table 2.2. The certificates that are issued at various stages of the certification process are described in next section.

Table 2.2 The functions of certificates

Certificate	Function
Complying development certificate	Development consent for complying development. Specifies conditions of consent.
Construction certificate	Certifies that specific building or subdivision work yet to be commenced will comply with regulatory requirements.
Compliance certificate	Certifies that a specified aspect of a development complies with regulatory requirements, either before work commences or after the work is complete.
Occupation certificate	May be issued for whole or part of building. Permits occupation of new building or change in building use. May be issued as an interim or final certificate.
Subdivision certificate	Authorises the registration of a plan of subdivision under the Conveyancing Act 1919.

The BPB accredits council certifiers and private certifiers under the BP Act. Under this Act, the BPB accredits certifiers into four grades in category A, one in category B, sixteen in category C and one category D as shown in Table 2.3. Category A is building surveyors. A1 certifiers are authorized to issue most certificates while A4 certifiers have little authority and can only conduct inspections required by principal certifying authorities. Accredited certifiers in category B focus on building subdivisions only while category C requires various accredited certifiers to assess and issue specific certificates such as drainage and electrical designs. Finally, category D emphasizes strata certification (Building Professionals Board 2013).

In addition, several statutes including the Building Professionals Regulation 2007, the EP&A Act and the Home Building Regulation 2004, require building practitioners to construct buildings that comply with the BCA. The BCA contains technical provisions that accredited certifying authorities need to adopt to assess the design and the construction works of buildings. An overview of the BCA as it relates to this study is provided in section 2.5 (at page 19).

Table 2.3 Categories of accreditations

A1	Accredited certifier - building surveying grade 1
A2	Accredited certifier - building surveying grade 2
A3	Accredited certifier - building surveying grade 3
A4	Accredited certifier - building inspector
B1	Accredited certifier - subdivision certification
C1	Accredited certifier - private road and drainage design compliance
C2	Accredited certifier - private road and drainage construction compliance
C3	Accredited certifier - stormwater management facilities design compliance
C4	Accredited certifier - stormwater management facilities construction compliance
C5	Accredited certifier - subdivision works & building works (location of works as constructed) compliance
C6	Accredited certifier - subdivision road and drainage construction compliance
C7	Accredited certifier - structural engineering compliance
C8	Accredited certifier - electrical services compliance
C9	Accredited certifier - mechanical services compliance
C10	Accredited certifier - fire safety engineering compliance
C11	Accredited certifier - energy management compliance (Classes 3, 5 to 9)
C12	Accredited certifier - geotechnical engineering compliance
C13	Accredited certifier - acoustics compliance
C14	Accredited certifier - building hydraulics compliance
C15	Accredited certifier - stormwater compliance
C16	Accredited certifier - speciality hydraulic services compliance
D1	Accredited certifier – strata certification

Source: (Building Professionals Board 2013: 7)

2.4.2 Certification Processes

Building projects in Australia must be assessed through a series of certification processes before the commencement of construction work. The NSW government provides developers with two approaches: Development Application (DA) – Construction Certificate (CC) and Complying Development Certificate (CDC) (Building Professionals Board 2011). The former applies to all building classes, whilst the latter is an alternative way of securing a DA and is specific to residential buildings. The CDC is not dealt with in this study because residential buildings are not considered within the research scope.

In terms of the DA – CC process, the first step is to lodge a DA with a local council. Several documents are required, with the minimum requirements being a Statement of Environment Effect, plans (including site plan, floor plans, elevations and sections) and a statement describing the proposed development. In most cases, the council issues the DA consent with conditions. Afterwards, the applicants have to hand in documents that comply with the said conditions to either council or accredited certifiers for the CC application.

The CC requires specifications and plans which describe the standards to which a building is to be constructed and defines the extent of building works by outlining their configuration, use, appearance as well as fire safety provisions. After issuing the CC (which allows applicants to carry out construction works), applicants need to arrange appointments with the principal certifying authorities for site inspections to obtain the Occupation Certificate (OC). Figure 2.2 shows the sequential process for each application stage.

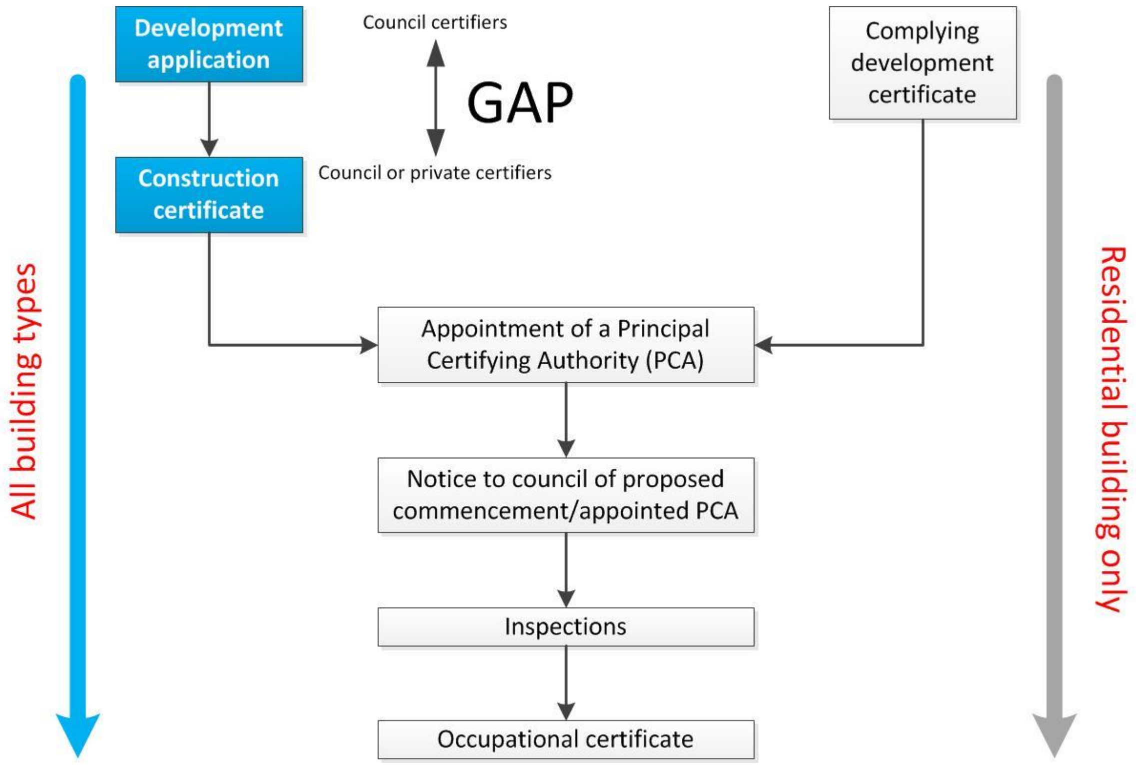


Figure 2.2 Building approvals process

Adapted from: (NSW department of Planning and Environment 2015)

However, some issues within the certification process are worth noting. Differences may arise between council and private certifiers with respect to granting of approvals for Development Applications and Construction Certificates. DA Conditions arise from local councils, who may ask for additional requirements to be met for building design development. Construction Certificates cannot be issued until these conditions are fully achieved. However, in some cases private certifiers may issue Construction Certificates relying on statements of intent without requesting adequate design drawings. Moreover, developers may be reluctant to provide engineering designs and rely on statements of intent and construction techniques (Wales and Gyles 1991). These situations are at the discretion of the certifying authorities and developers.

During the certification process, in addition to conforming to the DA conditions, building designs need to comply with building regulations, particularly the BCA. However, the BCA is a set of complex and ambiguous regulations that may result in issues when determining whether building designs comply. This is further discussed in the next section.

2.5 BCA for design compliance

The National Construction Code Series (NCC) as initiated by the Council of Australian Governments includes most regulations for design compliance (Australian Building Codes Board 2013). It comprises three volumes: Volume One pertains to Class 2 to 9 buildings; Volume Two pertains to Class 1 and 10 buildings, and; Volume Three pertains to plumbing and drainage associated with all classes of buildings. The Building Code of Australia (BCA) is Volume One and Volume Two of the NCC.

The focus of this study is on Volume One of the NCC. This document sets out regulative requirements in multiple sections including general provisions, structure, fire resistance, access and egress, services and equipment, health and amenity, ancillary provisions, special use buildings, maintenance and energy efficiency. These regulations assist building designs to reach the goal of the BCA, as stated

> ‘The goal of the BCA is to enable the achievement of nationally consistent, minimum necessary standards of relevant safety (including structural safety and safety from fire), health, amenity and sustainability objects efficiently.’ (Australian Building Codes Board 2013: 8)

According to the scope described in section 1.4 (page 5) and section 1.5 (page7), this study is restricted to commercial buildings and Section C Fire Resistance. These are introduced separately in the following sections.

2.5.1 Class of building

The building classifications (from Class 1 to Class 10) have been delineated in section 1.4 (page 5). Except for Class 1and 10 buildings, the BPB categorises building classifications into two groups: residential and commercial buildings. This study is restricted to commercial buildings because residential building designs can be assessed through the Complying Development Certificate process (which may not require complete design details before construction works commence). The commercial building classifications are outlined in Table 2.4.

Table 2.4 Classifications of Commercial Buildings

Class	Definitions	
Class 5	An office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.	
Class 6	A shop or other building for the sale of goods by retail or the supply of services direct to the public. Example: café, restaurant, kiosk, hairdressers, showroom or service station.	
Class 7	A building which is -	
	Class 7a	a car park.
	Class 7b	for storage or display of goods or produce for sale by wholesale.
Class 8	A laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing, or cleaning of goods or produce is carried on for trade, sale or gain.	
Class 9	A building of a public nature -	
	Class 9a	a health care building, including those parts of the building set aside as a laboratory.
	Class 9b	an assembly building, including a trade workshop, laboratory or the like, in a primary or secondary school, but excluding any other parts of the building that are of another class.
	Class 9c	an aged care building.

Source: (Australian Building Codes Board 2013: 42)

These building classifications are defined in accordance with the purposes for use and/or functions they can provide. However, several building classification contains multiple functions. This may result in accredited certifiers interpreting differently and thereby determine building classifications in an inconsistent manner. For example, various building practitioners may regard an assembly of people in a building for a particular activity as Class 6 or Class 9b. In the BCA 2008 (Australian Building Codes Board 2008), the classification of Class 6 use relates to any 'bar area' (which could include an assembly of people to meet, socialize and also possibly to be entertained), whilst the Class 9b classification also refers to a building where people may assemble to be entertained. Although the Class 6 building in BCA 2009 (Australian Building Codes Board 2009) refers to a 'bar area that is not an assembly building', this inconsistency can result in different assessments.

2.5.2 Section C Fire Resistance

Fire resistance is regulated through Section C of the BCA. Its main objective is to safeguard people from illness or injury and prevent loss of lives due to fire occurring in a building. It contains a performance hierarchy, and Deemed-to-Satisfy (DTS) provisions comprising three parts (Australian Building Codes Board 2013):

Part C1 Fire Resistance and stability: provides rules on how to determine the type of fire resisting construction for a Class 2 to 9 building. The type of fire resisting construction is based on the classification, rise in storeys, floor area, and volume, of a building.

Part C2 Compartmentation and separation: the intent of this part is to control the spread of fire between buildings and within a building by controlling the size of fire compartments, the location of openings in external walls that may allow fire to spread from one storey to another, the separation of different building classifications in a building by fire resisting construction, the separation of hazardous equipment, and the separation of equipment required to operate in the event of an emergency.

Part C3 Protection of openings: in a fire resisting construction, potential weak points may exist. Examples include doorways in a fire-resisting wall, service openings in a fire-resisting floor or wall, and windows in a fire resisting external wall close to a boundary or another building. This part intends to protect the openings from fire.

Specification C1.1 Fire-resisting construction: this specification contains requirements for the fire resistance level (FRL) of building elements (e.g. external/internal walls, columns and floors). Each Type of Construction sets the FRL criteria for specific building classes. In general, Class 7b and 8 need to reach the highest FRL of building elements while Class 2, 3 or 4 have the least requirements. Apart from these, it sets concessions specific to open-deck car parks that need comparatively low FRL requirements.

For the purpose of promoting fire safety and property protection, Abrahams (1999) describes five tactics (Figure 2.3) that assist stakeholders in providing for fire safety through the design process from inception to completion. The five tactics are Prevention, Communication, Escape, Containment and Extinguishment. They provide the fundamental framework within which stakeholders should work. A building designed with adequate consideration to these five factors will offer an acceptable level of fire safety.

The most influential of the tactics shown in Figure 2.3 to fire resistance codes is containment (Stollard and Abrahams 1999). Containment attempts to make fire selfcontained or slow fire spread and therefore provides life safety and protection of property. This involves the FRL of building materials as well as the sizes and volumes of fire compartments. Section C Fire Resistance emphasizes these in Part C1, Part C2 and Specification C1.1. These considerations have informed and shaped the development of the BIM-CCS in this study.

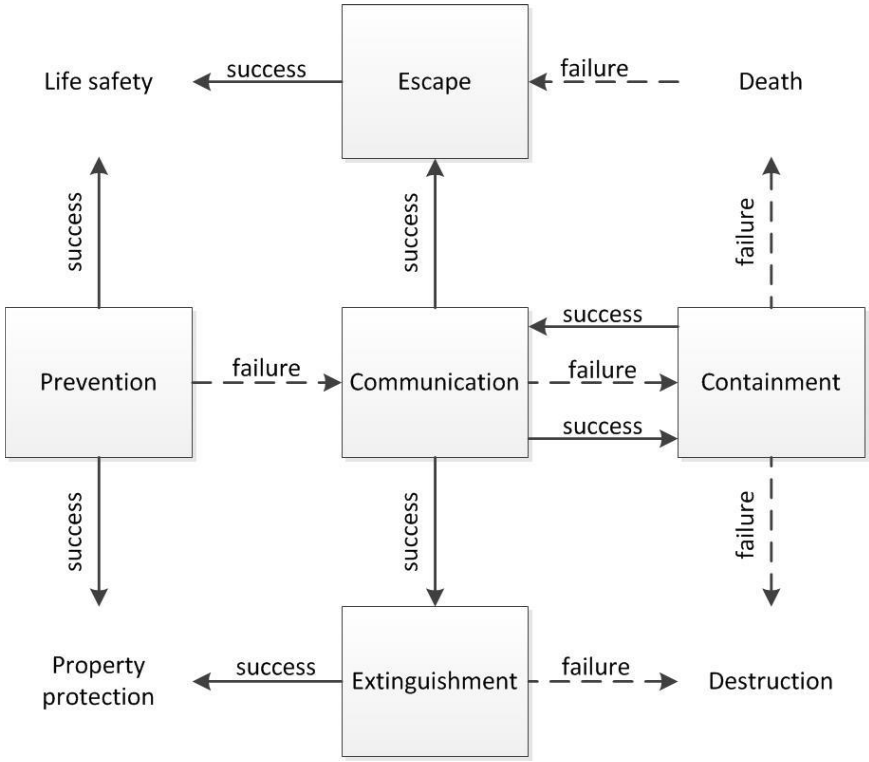


Figure 2.3 Matrix of tactics and objectives

Source: (Stollard and Abrahams 1999: 12)

2.5.3 BCA for certifying authorities and project teams

In Australia, project teams may not have the knowledge and skills to be able to assess their building designs for compliance with building regulations (Ding et al. 2006, Fischer, J. and Guy 2009). Certifying authorities and/or consultants are not involved in the design process or can only participate in at very late design stages (American Institute of Architects (AIA) 2007, InfoComm International 2011). This emphasizes the lack of awareness of building regulations because project stakeholders may see building regulations as a burden that restrains their creativity (Fischer, J. and Guy 2009, Hunt and Raman 2000).

In addition, in some cases, consultants and even certifying authorities interpret BCA clauses in an inconsistent manner (Fischer, J. and Guy 2009, Nawari 2013, 2012b). The aforementioned instance the bar area may be determined in either Class 6 or Class 9b before BCA 2009 (Australian Building Codes Board 2009). In such cases, the FRL of building elements can, for instance, be downgraded. This is a challenge for code-checking tools as ambiguities like these cannot be catered for.

2.5.4 A reform to the building regulations

The Australian Building Codes Board (ABCB) is a joint initiative of all levels of government of Australia that has made efforts to reform the regulatory framework since the BCA was created. Over the past two decades, the ABCB have carried out three major reforms. The first was to develop a single national technical code in the early 1990s. Then the ABCB introduced performance-based building codes in the mid-1990s. More recently, plumbing and construction were integrated into the National Construction Code in 2011.

A report by the Centre for International Economics (2012) entitled 'Benefits of building regulatory reform' points out that the current building regulatory reforms, over the last twenty years, have gained around $1.1 billion per annum in benefits (e.g. cost saving from efficient design and construction, and new building products and materials) while an additional $1.1 billion per annum in potential benefits has not been realised. The next instalment of building regulatory reform has been established in the 2014-15 ABCB Business Plan (Australian Building Codes Board 2014). The aims for these reforms are to:

- augment public access using a free online NCC, and prolong amendment cycle timeframe to increase the document's stability and useability;
- measure the NCC's performance quantitatively to strengthen its uptake and therefore can be applied as innovative and cost effective means to improve the quality of building design and construction;
- decrease the NCC departures between State and Territory, and to consolidate national regulation in a consistent manner;
- restrict the imposition of higher prescriptive standards for building design and construction than those agreed to nationally through the NCC by other authorities, such as local governments; and
- expand the NCC to cover all on-site building regulations into a single source document to maintain national consistency and remove unnecessary regulatory overlaps.

Many actions are also set out to achieve these goals. These include free access to the online version of the NCC, enhancing training and awareness of building-related professionals, as well as streamlining the NCC regulations. Of particular relevance to this research is the adoption of the digital NCC and new technology applications in 2018. This highlights the importance of using technology to enhance awareness of the BCA by users and to increase the consistency of compliance outcomes. These goals support this study and provide a clear focus for the development of a BIM-CCS for the Australian construction industry.

One solution to prevent such inconsistencies may be to use BIM-CCSs to assist in assessing whether or not design drawings comply with legislative requirements (Rogers 2012). BIM-CCS not only reduce inefficiencies due to the time and effort spent on manual process but facilitate consistency of designs compliance checking (Jeong, J. and Lee, G. 2010, Kiviniemi 2011).

2.6 Summary

Productivity and performance issues within the construction industry are complex. An obvious issue is that additional expense may result from building designs that do not satisfy the requirements of the BCA during the certification process. However, few tools are available that assess whether designs comply with building regulations. Many studies agree that design errors result in additional costs related to time and labour (Costa, D.B. and Formoso, C.T. 2010, Kiviniemi 2011, Smith, J. and Jaggar 2007). If these errors are identified and remedied at an early stage, these costs can be reduced. This study focuses on the ways stakeholders can be assisted to assess their designs instantly during the design process. This enables them to ensure their designs comply with BCA requirements before submitting them to certifiers. In addition, the BCA needs to be interpreted in a consistent manner and this is currently not always the case (Fischer, J. and Guy 2009, Nawari 2013, 2012b). Several key issues and research questions arise from this chapter.

Key issues

K2.1 Stakeholders may lack knowledge of the BCA and may not be able to assess whether or not their designs comply with the requirements of the BCA during the design process.

K2.2 Design issues and variations may occur late in the design stage, certification process or construction stage because design compliance-related disciplines rarely assist stakeholders to assess building designs during the early stages of design.

K2.3 The manner in which some building codes are expressed is ambiguous. This can result in different certifiers having different interpretations of the same regulation.

K2.4 The certification process is a sequential process. If building designs do not comply at any stage, additional expenses are likely to increase.

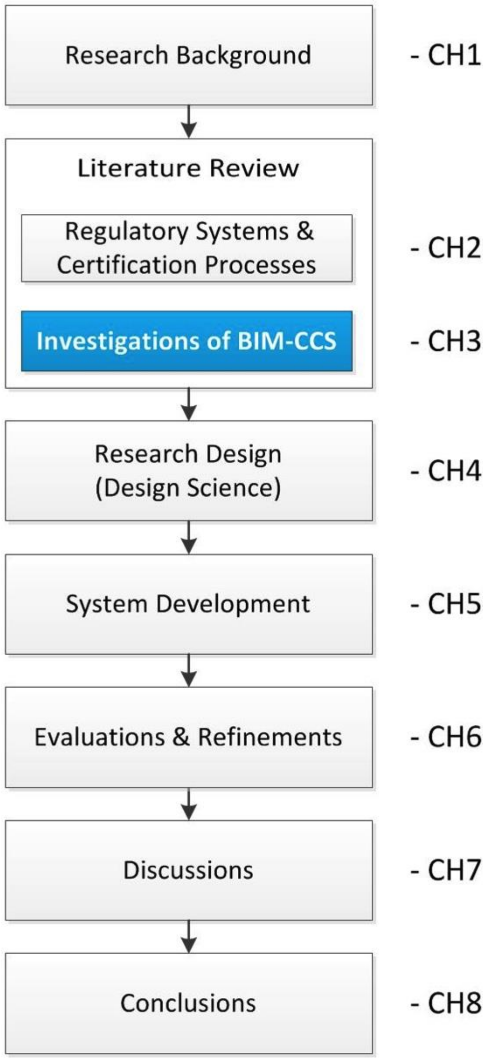
K2.5 Governing bodies (ABCB) are currently setting goals for the use of technology to enhance users' awareness of the BCA and to improve the consistency of compliance works.

Research Questions

Q2.1 How can technology assist in assessing designs for compliance with building regulations during the design process?

Q2.2 What can be done to assist in interpreting the BCA in a consistent manner?

3 AN INVESTIGATION OF BIM-ENABLED CODE-CHECKING SYSTEMS



3.1 Introduction

This study applies information technologies (IT) to code compliance activities to mitigate issues arising from manual certification (as described in Chapter 2). IT-based building technologies have been utilized to facilitate multiple design works (e.g. 3D modelling and scheduling) during the design process (Brewer et al. 2003, Sarshar et al. 1999). Building information modelling has been promoted as a means of producing data-rich models for multiple uses for different disciplines (Azhar 2011, Grilo and Jardim-Goncalves 2010, Kiviniemi 2011). This implies that BIM can potentially be used to support code compliance checking activities (Nawari 2013, 2012b, 2012a). Hence this chapter explores BIM and how it can assist code-checking systems.

This chapter firstly investigates the ways IT-based building technologies have been applied in building designs (Section 3.2). This includes the progress and benefits IT technologies bring to building designs. Section 3.3 introduces the concept of BIM and how BIM influences the design process for stakeholders. It then explores BIM characteristics and capabilities (Section 3.4). This highlights how BIM supports code-checking activities for multiple disciplines during the design process. Section 3.5 and section 3.6 each review BIM-based rule engines and existing code-checking systems in relation to rule designs, BIM models, execution platforms and reporting systems. The factors influencing the ways code-checking systems work are then discussed. Finally, Section 3.7 discusses the BIM uptake strategies in Australia.

3.2 IT in construction industries

Building projects produce and communicate vast amounts of information. This highlights the significance of effectively integrating information for stakeholders (Brewer et al. 2003). Information Technology (IT) can underpin this integration. It enables the information of building designs to be created, managed, stored and exchanged between stakeholders in a digital and visualized environment (Borchers 2009, Young, N. W. et al. 2008). This strengthens communication, efficiency and coordination for building designs from design through construction for the entire lifecycle of a building project (Succar 2010a, Volk et al. 2014). Incorporating IT in building projects has been shown to reduce time, cost and improve quality outputs (Sarshar et al. 1999).

Various IT tools have been applied in construction industries. Various studies highlight the benefits that computer aided design (CAD) technologies bring to project stakeholders (Fischer, M. 1993, Satti and Krawczyk, R. J. 2004, Schodek 2005). Figure 3.1 illustrates the different stages in which technology has progressed in these industries (Becerik 2004). The technology initially used to prepare building designs is in the format of 2D CAD drawings. This starts with geometric elements (such as lines, circles and arcs), assembles them as readable objects (such as doors and walls) and groups objects to generate different spaces and functions (such as a bathroom and a bedroom). However, the grouping of objects lacks strict universal standards and hence can be an error-prone activity. This may hinder developing 2D CAD extensions such as code compliances.

3D CAD was subsequently developed as a visualization tool, containing objects with explicit functional descriptions as well as design parameters (Kim, J. et al. 2008). In contrast to grouping lines and arcs as a defined object (as in 2D CAD drawings), objects in 3D CAD models are all predefined with relative attributes (e.g. a window comprises frames, layers and tracks) (Schodek 2005, Spence et al. 1994). Moreover, stakeholders can explicitly define or modify spaces or rooms and their properties during the design process. For example, a space can be tagged as a bathroom with various properties such as egress, accessibility, door swing, light fixtures, fire assistance and so on. However, stakeholders may only tag some functions of spaces and components or not correctly tag them all. Furthermore, some object definitions within CAD software differ from vendor to vendor (Ito 1989, Kim, J. et al. 2008). In addition, other software may not easily recognize these definitions when designers collaborate with each other. This may limit the capabilities of 3D CAD. Some objects therefore may not easily be analysed for various purposes when a model lacks attribute definitions or where the model has been created with different definitions for attributes (Han et al. 1997).

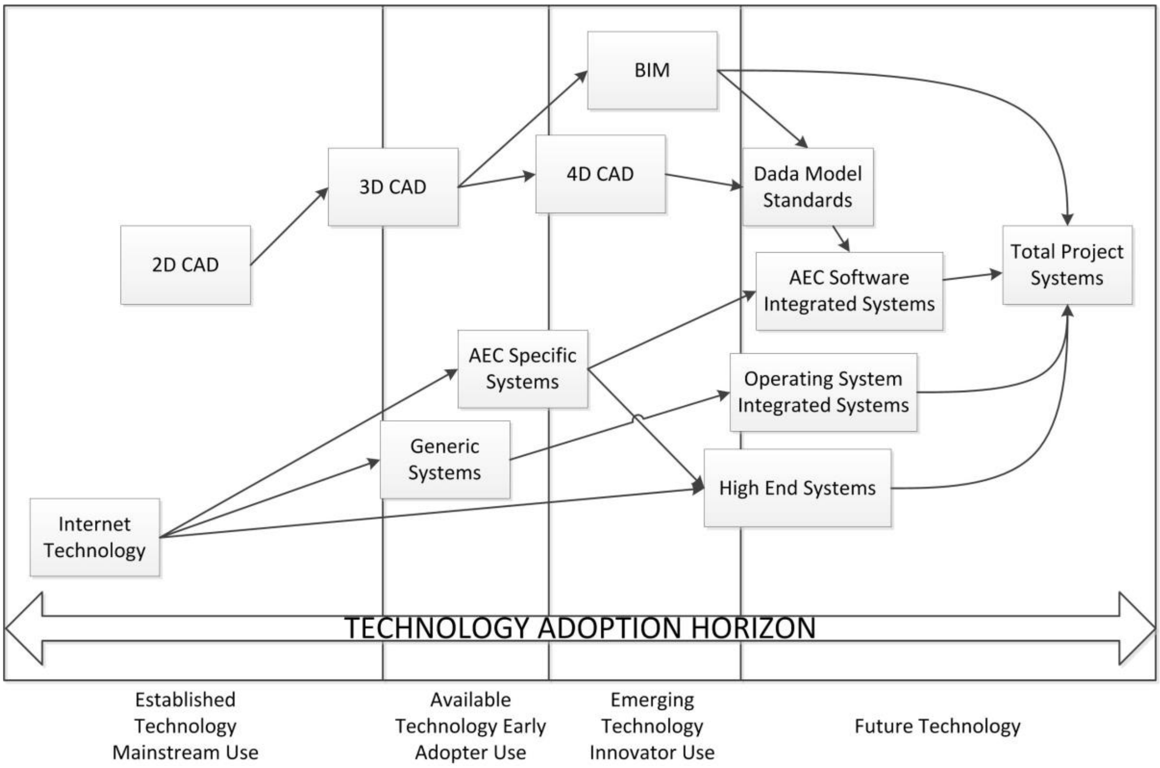


Figure 3.1 Trend of use of IT in AEC industry

Source: (Becerik 2004: 245)

BIM has been increasingly utilized to develop building project designs for various construction-related industries. It assists by enhancing stakeholders' communications, co-ordination and collaborative activities (Azhar 2011, Kiviniemi 2011, Volk et al. 2014). In addition, BIM models contain rich information, which may be extended for various purposes (e.g. cost estimations) (Kreider et al. 2010, Seo et al. 2012). Applying BIM to design compliance can potentially mitigate issues relating to inconsistent assessment by manual certification activities (Nawari 2013, 2012a). A further exploration of BIM technology is described in the following sections.

3.3 BIM technology

BIM technology is a vehicle that enables data-rich models to be built for both internal and external communications (Azhar 2011, Deutsch 2011). Numerous BIM features such as clash detection, scheduling and risk management have proliferated (Kim, H. et al. 2013, Nisbet, Nick and Dinesen 2010, Seo et al. 2012). Using BIM to assist with design compliance is an area that has become increasingly practical with the continuing development of BIM tools (Nawari 2013, Yang and Li 2001). BIM has been widely adopted in the construction industry. It has been shown to be an effective vehicle for improving collaboration, enhancing communication, strengthening coordination and increasing the productivity of stakeholders (Babič et al. 2010, Grilo and Jardim-Goncalves 2010, Succar 2009). Some see BIM as an advanced CAD technology but BIM extends far beyond this. BIM represents processes, policies and technologies affecting the ways all stakeholders collaborate and enables building designs to be managed and coordinated through their entire lifecycle (Succar 2009). The following sections compare BIM definitions and discuss the benefits and barriers that BIM can bring into design processes.

3.3.1 What is BIM

The concept of BIM was initiated in the 1970s (Eastman, Charles M. et al. 1974). The term “Building Information Model” was firstly used by G.A. van Nederveen and F. P. Tolman (van Nederveen and Tolman 1992). However, it had not been widely adopted until 10 years later when *Autodesk®* released the white paper entitled "Building Information Modelling" (San 2003). Since then, research increasingly focuses on BIM and its effects. Many studies address the ways that BIM influences building designs from various perspectives. Some pertinent definitions of BIM are shown in Table 3.1. This table represents different disciplines’ views of BIM. Some define BIM by viewing its effects on the entire lifecycle of a building project while others definitions of BIM concentrate on its technical abilities to assist project teams. There are no explicit BIM definitions that all disciplines agree with. For the purposes of this study, BIM is defined as **a synergy between technology, process and policy enabling stakeholders to coordinate, update and share design information throughout the entire building lifecycle.**

BIM has been adopted to enhance and improve design performance in building industries worldwide. Significantly, it provides a collaborative environment that brings all building-related disciplines together to design, construct and manage a building project. In addition to the geometric properties of length, width, and height, BIM contains object-oriented information including specifications, finishes, fire ratings and many parametric data that users can add (Ibrahim, M. et al. 2004). BIM's key benefits are at present being exploited by the leading exponents in the industry. They include incremental data established by all team members, creating a feedback loop that streamlines project delivery resulting in quality improvement as well as substantial and waste reduction, and time and cost savings (Azhar 2011, Hummels and Frens 2009). BIM is seen as a powerful tool in facilitating building management (Arayici et al. 2011, Kymmell 2008).

Table 3.1 BIM definitions

Definition description	Source
BIM is a 3D object database that can be easily visualised, has rich data and structured information. Building Information Modelling is a process of representing building and infrastructure over its whole life cycle from planning, design, construction, operations, maintenance and recycling.	(buildingSMART Australasia 2012: 7)
A project simulation consisting of the 3D models of the project components with links to all the required information connected with the project's planning, construction or operation, and decommissioning.	(Kymmell 2008 p.28)
BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition	(The National Institute of Building Sciences and buildingSMART alliance 2012: 22).
In the context of the construction and civil engineering industries, BIM is a process that relies on computerized virtual 3D model of a building (or a construction or civil engineering project or some other facility, but which, for the ease of future reference, will simply be referred to as a 'building') which reacts to changes in the same way that actually constructed building would.	(Barnes and Davies 2014: 5)
Building information modelling solutions create and operate on digital databases for collaboration, manage change throughout those databases so that a change to any part of the database is coordinated in all other parts, and capture and preserve information for reuse by additional industry-specific applications.	(San 2003: 9).
We define BIM as a modelling technology and associated set of process to produce, communicate, and analyse building models.	(Eastman, C. M. et al. 2008: 16)
BIM is an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle.	(National Institute of Building Sciences (NIBS) 2008: 8)

3.3.2 Uptake of BIM in Australia

BIM and its extensions are not fully utilised within the construction sectors in Australia. The construction sectors are notorious for being less productive, of lower quality and investment value than other sectors of the economy (Cole 2002, Wales and Gyles 1991).

Improvements are possible with the use of BIM technology, while other factors including culture, management, processes, and policies related to BIM may also impact the implementation of BIM. The industry is now at a crucial stage of a major shift of technology and process innovation. The Building the Education Revolution (BER) Implementation Taskforce (2011) report – Building the Education Revolution Final Report – addresses a number of construction industry-wide issues, including:

- Inadequate use of technology to deliver coordinated project design documentation;
- Substandard workmanship which may be a result of low completion rates of trade apprenticeships;
- A trend to generic skills for project managers rather than technical qualifications backed by significant hands-on construction experience; and
- On occasion, insufficient collaboration across the professions resulting in poor project scoping and inadequate documentation coordination (2011: 11).

A survey conducted by buildingSMART Australia (Figure 3.2) illustrates the proportion of people in each subsector of the buildings network that are currently using BIM technology (buildingSMART Australasia 2012). According to the survey, engineers and contractors are the highest users of BIM (75%). Notably, 49% of architects indicated that they currently use BIM, while 18% indicated that they do not.

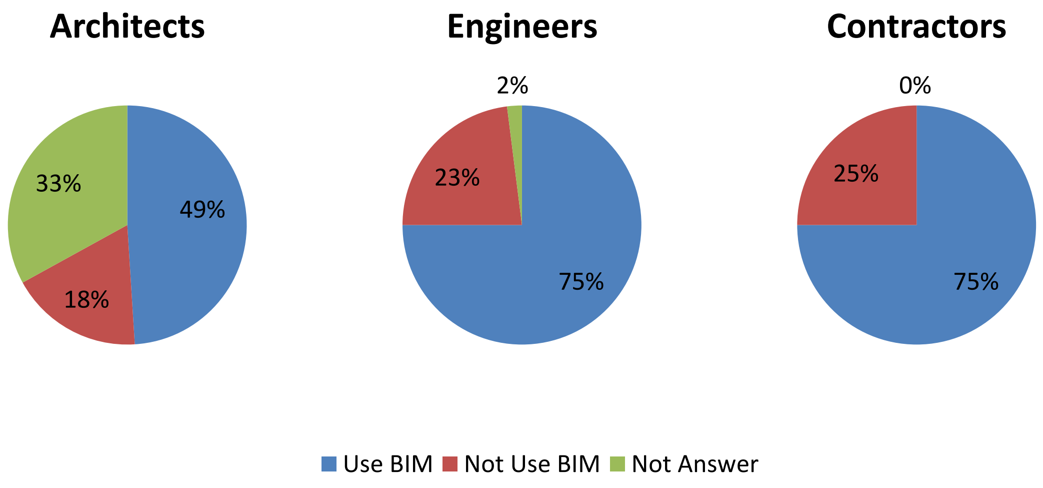


Figure 3.2 A survey of BIM adoption in Australia

Source: (buildingSMART Australasia 2012: 12)

In Australia, BIM represents a coordinated and consistent approach that multiple disciplines and sectors of the construction industry seek for the entire construction industry. The Federal Government and buildingSMART (2012) have released a strategic report – the National BIM Initiative (NBI) – outlining the support needed to drive the construction industry to implement BIM. To successfully execute the NBI, multiple disciplines need to engage to achieve maximum productivity, improve working practices and increase BIM uptake across the entire project lifecycle. The NBI report (buildingSMART Australasia 2012) provides a guide to bring together all parties involved in construction processes and work together on initiatives and ensure the views of all relevant parties are recognised and resolved. Moreover, it offers a chance to drive the accelerated adoption of BIM in Australia and drive productivity benefits throughout the entire economy.

3.3.3 How BIM effects design processes

Incorporating BIM into design processes enables multiple disciplines to collaborate on a communicable platform in coordinated and informative ways (Ireland 2009, Sacks, R. and Barak 2008). This shifts their engagement towards the design stage, and thereby reduces risks of variations at later stages. In addition to cross-disciplinary collaboration, the Australian Institute of Architects (AIA) (2007) proposes a redefinition of phases driven by two key concepts: the integration of early input from multiple disciplines; and the adoption of BIM technology to create models and simulations for projects. These two concepts promote the level of design completion before the documentation phase commences. Thus the first three phases of an integrated BIM project include: Conceptualization, Criteria Design, and Detailed Design (shown in Figure 3.3). This involves an increased level of collaboration compared to that required in traditional processes.

An estimated increase in productivity for structural engineering practices adopting BIM is up from 15% to 41% (Sacks, R. and Barak 2008). Other benefits including improved profitability may also be found, with some citing returns on BIM investments of up to 94.86% (Azhar et al. 2008a), caused by the elimination of on-site clashes and the associated saving of time.

Compared to the traditional Construction Documents phase (American Institute of Architects (AIA) 2007), Figure 3.3 shows that collaboration in earlier project stages requires less effort during the Implementation Documents phase of BIM integrated design processes. Moreover, the early participation of regulatory agencies and trade contractors facilitates shortening the Agency Permit and Bidding stage as well (American Institute of Architects (AIA) 2007). These activities facilitate the coordination of a project to a much higher level prior to commencing construction work, thereby achieving a more efficient Construction phase and a potentially shorter construction period (Deutsch 2011). BIM brings with it the requirement for those producing a building model to have more knowledge of the construction process, such as knowing exactly what is involved in the construction of “the real-world object” (Lee, Ghang et al. 2006: 765). This requires personnel with expertise and experience in BIM, technical knowledge, awareness of the BCA and building regulations as well as the involvement of multiple disciplines (Kaner et al. 2008). However, some studies indicate that design members may lack awareness of building regulations. In such instances, building designs still need to be assessed for compliance by consultants before lodgement with councils (Oster and Quigley 1977, Ralph 2001).

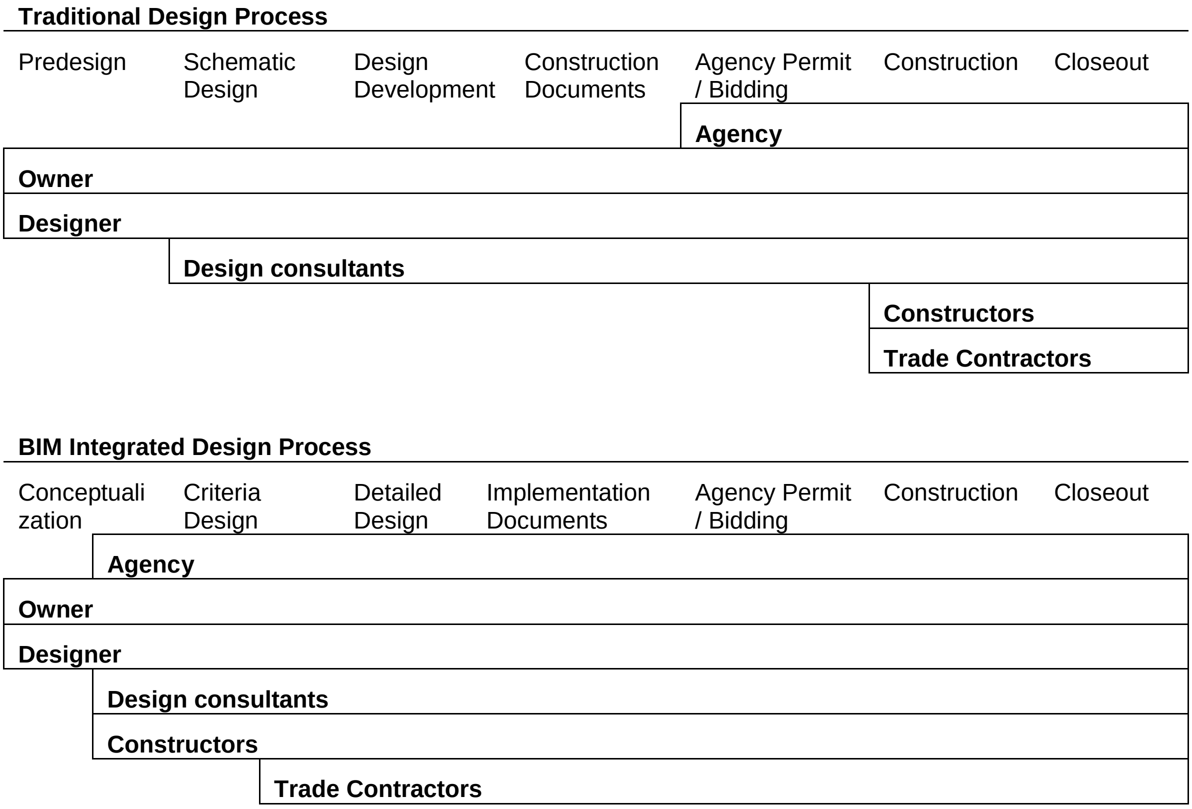


Figure 3.3 Comparison between Traditional Design Process and BIM integrated Design Process

Adapted from: (American Institute of Architects (AIA) 2007: 22)

InfoComm International (2011) also categorized progress from the Traditional Design Process to BIM Integrated Process into six factors (Table 3.2). Traditional design methods are criticised as being inefficient due to the discrepancies between various disciplines. When knowledge needs to be transferred between stakeholders, such as from a design team to a contractor, fragmented information may result from the use of paper-based documents. Moreover, a team member’s success only belongs to individuals rather than the overall success of the project team. Compared to traditional

CAD-based design, BIM Integrated Design merges project stakeholders in shared, trusting and collaborative approaches from the early design stage (Arayici et al. 2011, Deutsch 2011). BIM is a digital platform that provides substantial benefits for the whole design process and allows for the manipulation of collaborative data (Seo et al. 2012). In addition to improving efficiency and productivity, BIM allows a team to manage and control risks in the design phase (Azhar et al. 2012, Eastman, C. M. et al. 2008).

Some authors see this “process shift” as positive progress in improving quality and cost effectiveness as well as promoting greater collaboration between project team members (Young, N. W. et al. 2008). However, most agree that resistance to change is a key factor in preventing the uptake of BIM (Bernstein, P. G. and Pittman 2004, Yan and Demian 2008).

Table 3.2 A comparison of Traditional Design vs. BIM Integrated design methods on key project processes

Project Factor	Traditional Design Process	BIM / Integrated Project Delivery
Team	Fragmented, assembled on “as-needed” or “minimum necessary” basis, very hierarchical, controlled	Integrated team entity of key stakeholders, assembled early in the process, open, collaborative
Process	Linear, distinct, segregated, knowledge gathered “as-needed”, information hoarded, silos of knowledge and expertise	Concurrent and multi-level, early contributions of knowledge and expertise, information openly shared, trust and respect
Risk	Individually managed, transferred to the greatest extent possible	Collectively managed, appropriately shared
Reward / Compensation	Individually pursued, minimum effort for maximum return, often first cost-based	Team success tied to project success, value-based
Communication / Technology	Paper-based, two dimensional, analogue	Digital, virtual, BIM, 5+ dimensional
Agreements	Encourage unilateral effort, allocate and transfer risk, no sharing	Encourage, foster, promote and support multilateral open sharing and collaboration, risk sharing

Adapted from: (InfoComm International 2011)

According to Figure 3.3 and Table 3.2, project stakeholders, in traditional design processes, may encounter issues such as fragmented information, segregated management and time being wasted. However, these issues can be mitigated when BIM is adopted by team members, and this should result in improved performance and productivity (Amor 2008, Succar 2010a, Suermann 2009, Young, N. W. et al. 2008). Moreover, BIM-integrated design processes have the potential to enable stakeholders to explore compliance issues in the course of collaborating with their colleagues before construction work commences.

3.3.4 BIM software

BIM is not only CAD technology, but represents a vehicle that allows stakeholders to collaborate and integrate BIM data from various BIM software packages on a communicable platform. There are many BIM extensions available to stakeholders and it is usual for those collaborating on the design of a project to use several of them. Some BIM software is developed for specific uses and is focused on specific professionals. BIM software generally can be categorized into six groups for specific disciplines: (1) architecture, (2) structure, (3) mechanical, electrical and plumbing (MEP), (4) construction, (5) sustainability and (6) facility management. Table 3.3 identifies some of the BIM software that practitioners are currently using for these practices (buildingSMART 2010).

Table 3.3 BIM software providers

Architecture	Structures	MEP	Construction	Sustainability	FM
• Autodesk Revit Architecture • Graphisoft ArchiCAD • Nemetschek Allplan Architecture • Gehry Technologies - Digital Project Designer • Nemetschek Vectorworks Architect • Bentley Architecture • 4MSA IDEA Architectural Design (IntelliCAD) • CADSoft Envisioneer • Softtech Spirit • RhinoBIM (BETA)	• Autodesk Revit Structure • Bentley Structural Modeller • Bentley RAM, STAAD and ProSteel • Tekla Structures • CypeCAD • Graytec Advance Design • StructureSoft Metal Wood Framer • Nemetschek Scia • 4MSA Strad and Steel • Autodesk Robot Structural Analysis	• Autodesk Revit MEP • Bentley Hevacomp Mechanical Designer • 4MSA FineHVAC + FineLIFT + FineELEC + FineSANI • Gehry Technologies - Digital Project MEP Systems Routing • CADMEP (CADduct / CADmech)	• Autodesk Navisworks • Solibri Model Checker • Vico Office Suite • Vela Field BIM • Bentley ConstrucSim • Tekla BIMSight • Glue (by Horizontal Systems) • Synchro Professional • Innovaya	• Autodesk Ecotect Analysis • Autodesk Green Building Studio • Graphisoft EcoDesigner • IES Solutions Virtual Environment VE-Pro • Bentley Tas Simulator • Bentley Hevacomp • DesignBuilder	• Bentley Facilities • FM:Systems FM:Interact • Vintocon ArchiFM (For ArchiCAD) • Onuma System • EcoDomus

Source: (buildingSMART 2010)

This study focuses on the architecture discipline's use of BIM software (Table 3.3 shows many BIM software providers). *Autodesk® Revit®* and GraphiSoft ArchiCad are the BIM tools that most stakeholders use to develop building projects. A survey conducted by Malleson (2014) showed the market share of BIM vendors in figure 3.4. It reveals that *Autodesk® Revit®* has the largest market share (49%), whilst GraphiSoft ArchiCAD is second (18%).

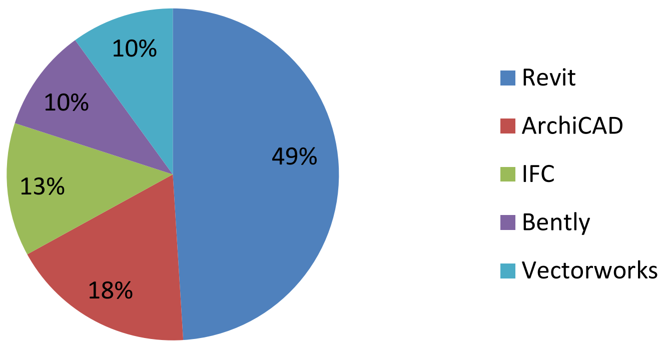


Figure 3.4 BIM software vendors and their market share

Source: (Malleson 2014: 20)

The technical issues for the largest two BIM software providers, *Autodesk® Revit®* and GraphiSoft ArchiCAD, warrant further discussion. Both of them are proven BIM tools that enable high quality parametric and object-oriented models to be produced and assembled in a single database file. Both programs use embedded template files that enable stakeholders to engage in design activities without the need to set environmental parameters. Table 3.4 compares several technical aspects of Revit and ArchiCAD.

Features that allow for extension and interoperability are two significant requirements that need to be discussed. Most BIM software is able to communicate with other BIM software but there remain issues for complete interoperability. When it comes to exchanging BIM models using IFC files, both Revit and ArchiCAD work well for exporting files and are able to create flawless projects in the new exchange format: IFC 2x3 schema. However, when importing IFC files (exported from another program) into Revit or ArchiCAD project files, issues are encountered including geometrical disconnections and loss of properties of building elements (buildingSMART 2009c, Lê et al. 2006). These issues require the model to be adjusted to ensure building objects are displayed correctly.

Table 3.4 Comparison between Revit and ArchiCAD

	Revit	**ArchiCAD**
Developers	Autodesk, USA	GraphiSoft, Hungary
Platform for disciplines	Three built-in versions adapted to architects, construction engineers and installation engineers.	One version suitable for most professions but needs Add-ons for MEP.
Sketching techniques	Uses continual measurement hanging chains that are fixed to the building objects.	Distances can be manually typed in to ensure that the values matching the requirements. Dimensional adjustments are more flexible.
Object library	Work with object types and family (library). Building elements are parametrically related to each other.	Objects are programmed with a technology called GDL that can be customized with flexible parameters.
Large projects	Well-coordinated and managed abilities.	May encounter errors when dealing with complex assembled models.
Extensions (plug-ins)	Free and supported by an online community. Free APIs allow programmers to develop plug-ins.	Supports few available plug-ins developed by several landmark vendors such as Solibri and Tekla.
Interoperability (IFC support)	Fully supports IFC 2x3 and previous versions.	Fully supports IFC 2x3 and previous versions.
File data (based on the same building design)	Large file data.	Smaller (about 1/3 of Revit file data).

Source:(Azhar et al. 2008b, Guan-pei 2010)

When considering the advantages and disadvantages of Revit and ArchiCAD, it is important to focus on the most basic functions of BIM. Both programs are effective BIM systems and exchanging IFC data generally progresses flawlessly. However, when a close comparison was made, it is clear that each program has its advantages (Broquetas 2010). For this study, the market share, interoperability and extension abilities are the main concerns.

3.3.5 BIM extensions

BIM has been successfully exploited for various extensions ranging from documentation and coordination through to clash detection and phase planning. A study of the frequency of use and the perceived benefits of twenty-five BIM extensions including code-checking (referred to as code validation) is outlined in Figure 3.5 (Kreider et al. 2010). Statistical analysis identifies 3D Coordination and Design Reviews as having the majority of use and the most perceived benefit while Building Maintenance Scheduling and Disaster Planning provide the least. Code-checking is ranked nineteenth. This may result from it not having been implemented in the construction industry. However, as conditions supporting code-checking activities continue to develop, BIM-enabled code-checking systems should become more prevalent.

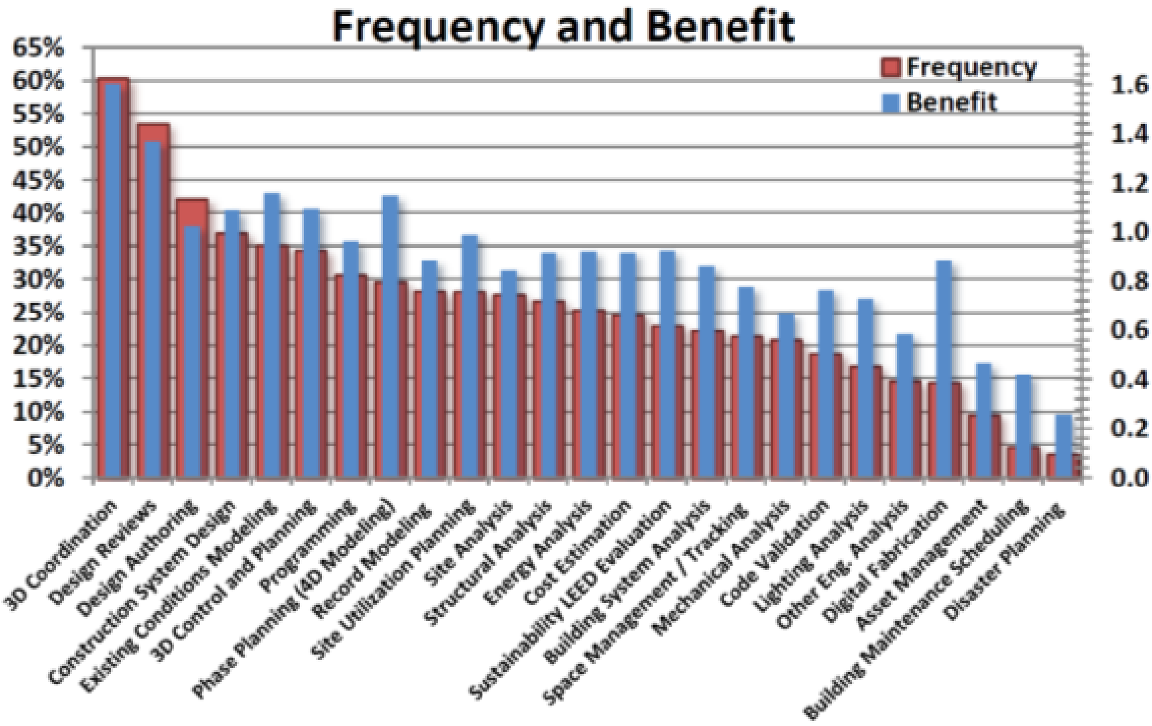


Figure 3.5 Bar Chart Comparing Frequency of Use Relative to Perceived Benefit

(Source from: Kreider et al. 2010)

McGraw Hill (2007) conducted a similar investigation of architects, engineers, contractors and owners, showing positive results for code-checking extensions (Figure 3.6). Architects agreed that code-checking using BIM had great potential. 85% of architect participants expressed interest in code-checking technology compared to 42% of contractor participants. This high interest reflects the fact that architects should be responsible for producing designs that need to comply with building regulations (Costa, D.B. and Formoso, C.T. 2010, Jeong, Y.-S. et al. 2009, Love et al. 2004). In terms of the time spent on code-checking activities (shown in Figure 3.7), approximately half the architects (48%) spent 26 hours or more ensuring their designs comply with building regulations. This report concludes that few architects have used code-checking related technologies because of the limited BIM extensions available at the time.

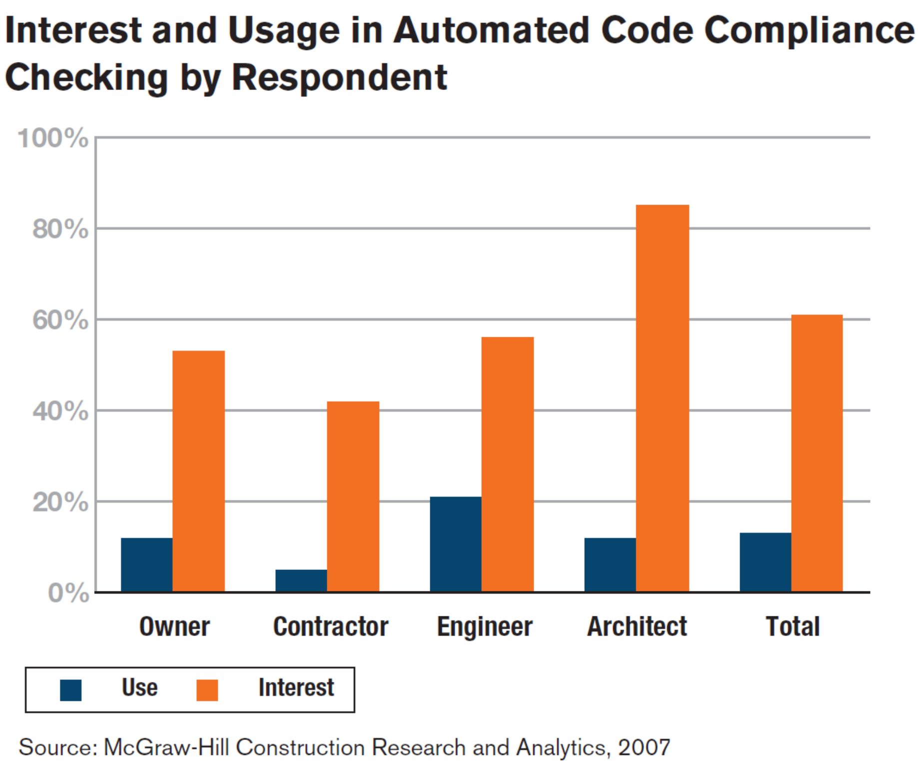


Figure 3.6 Interest and usage in code-checking by respondents

Source: (McGraw Hill Construction 2007: 23)

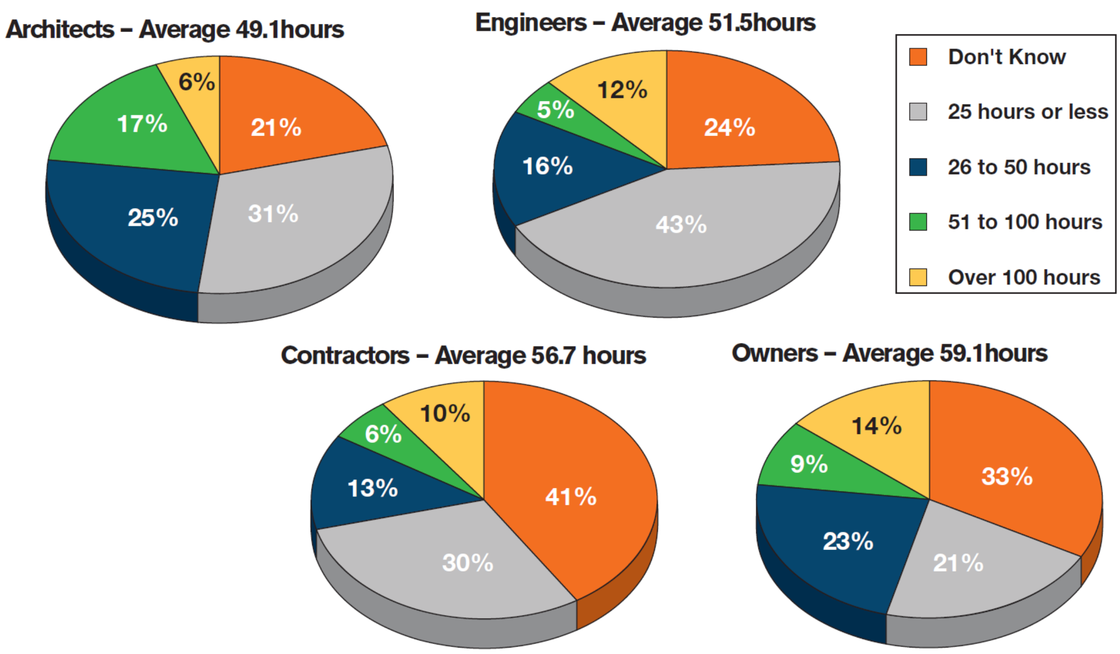


Figure 3.7 Time spent on code-checking per project

Source: (McGraw Hill Construction 2007: 23)

3.4 BIM characteristics for code-checking

BIM has demonstrated to have potential to assist various design activities. Section 3.3.5 (page 37) has outlined BIM capacities that have been successfully extended for various purposes (e.g. cost estimations and clash detections). These extensions may emphasize using specific information (e.g. geometry or semantics) and functions (e.g. visualizations or draft coordination). However, there are not many studies extending BIM in code-checking activities and identifying what BIM characteristics can assist code-checking activities. This section describes the characteristics of BIM that may assist this study to build the BIM-CCS, *Ignis*.

3.4.1 Object-orientation

BIM is differentiated from traditional CAD tools that usually use entity objects to represent geometry information (Ibrahim, Magdy and Krawczyk, Robert 2003). BIM provides an object oriented platform. The BIM objects contain geometry and semantic parameters and rules between these parameters (Eastman, C. M. et al. 2008, Solihin, W. and Eastman, C. 2015). For example, a window contains geometric parameters of length, width and thickness. A rule can be embedded in a window to use these parameters to produce volumes and weights. These objects may also have semantic parameters that code-checking activities may use. For instance, a fire door needs to be constructed out of fire resistant materials that comply with the required fire resistance levels. Semantic parameters may be created to incorporate these requirements. Most of parameters are predefined in object libraries. In addition to using these objects directly, stakeholders are allowed to create parameters for specific purposes in their designs(Barnes and Davies 2014, Eastman, C. M. et al. 2008).

3.4.2 Parametric

The properties of BIM models are parametric, and are thus able to generate data (e.g. quantities and volume) that analysis software needs (Kaner et al. 2008). BIM software automatically updates the data whenever changes are made to the model (Azhar et al. 2008a, Alder 2006). For example a window may need to be set a distance of 2 meters from a boundary wall. When and if the wall is modified, the distance from the window to the boundary wall must remain at 2 meters.

3.4.3 Coordination

A significant benefit of BIM is improved coordination of documents between stakeholders involved in the design phases of a project, as well as the coordination of building structural elements, both with other structural elements and with building services systems (Bedwell et al. 2012, Tatum and Korman 2000). Khanzode, Fischer, and Reed (2008) found that labour savings of up to 30% were possible through improved services coordination due to BIM. The coordination benefits of BIM were also found to apply to specialist trade subcontractors such as precast concrete and structural steel manufacturers, who found that “pre-building” their part of a project could help to significantly “reduce the likelihood of errors” that could occur on the construction site (Kaner et al. 2008: 112).

3.4.4 Interoperability

One of the major benefits mentioned in literature is the interoperability between the various BIM software packages. Interoperability is a major requirement to ensure that the construction industry obtains further efficiencies as a result of the use of BIM (Amor 2008), highlighting the importance of different software packages being able to communicate with one another. Interoperability implies one BIM package being able to use and modify BIM models produced in another. The International Alliance for Interoperability (IAI) has established the Industry Foundation Classes (IFC) standard for BIM models (Suermann 2009). IFC features a platform neutral, open file format that enables model data to be communicated between software packages and not controlled by specific vendor (Pazlar T 2008, Plume and Mitchell 2007).

Software vendors continue to endeavour to address the issues of interoperability and software compatibility and to improve communication between different packages without any loss of the intelligent BIM data. For example, the Autodesk Revit software includes specific modules for Architecture, Structural, and Services (MEP) which are combined in one system. All of these are fully compatible with each other (Gu and London 2010). This high interoperability of IFC-based BIM models assists design compliance and analysis activities to facilitate assessment of BIM models provided by different disciplines and software vendors.

However some literature notes that the translation of IFC-based models into other BIM systems is not fool-proof and that some data may be lost, particularly the parametric rules (Amor 2008, Chang et al. 2010). This is because some IFC schema (such as IFC 2X2 or IFC 2X3) cannot deal with parametric rules (buildingSMART 2009a, Pazlar T 2008). Important parameters may be lost when IFC data is exported from one vendor’s product to another. This is the challenge IFC developers face and may influence them to encourage software developers to design plugins to enhance their appeal of their BIM software. For example, both *Autodesk® Revit®* and ArchiCAD have developed their own plugins to transfer BIM model data between them.

In addition, the information description required for code-checking may differ from the IFC schema. For example, a water closet is a well-known description in Australia but is represented as a "sanitary flow inlet" in other international IFC schemas (Greenwood et al. 2010).

3.4.5 Visualization

BIM allows building designs to be constructed virtually in a digital environment prior to construction work commencing. The use of 3D visualizations in the early design stages, or prior to construction, allows stakeholders to enhance their understanding of their designs (Suermann 2009). 3D visualizations can also apply to other areas, such as clash detection, structural analysis, safety analysis and avoiding of design errors (Kim, H. et al. 2013, Seo et al. 2012).

3.5 BIM-based rule engines

Many BIM-CCSs create code-checking rules using rule engines. The rule engine can assist programmer designing rules in an efficient way because it may have embedded rule templates that the programmers can directly use. Rule engines for CAD models have been developed for various purposes including thermal analysis and code-compliance checking (Garrett Jr and Fenves, Steven J. 1987). However, effective rule checking systems are immature and few are commercially available at present. This section outlines four platforms that have been developed to support rule checking through BIM technology.

Solibri Model Checker (SMC): This is a java-based platform that can read the properties of IFC-based BIM models and visualize these models using the Solibri Model Viewer. It contains built-in functions including model pre-checking and 3D presentation of checking issues. Model pre-checking can detect whether models overlap or properties are missed. When issues are identified, SMC is able to highlight issues in 3D views and these can be used to produce reports. SMC provides rules for checking accessibility and space (Solibri 2007). SMC also has pre-defined rules for ISO accessibility and these are embedded in the system. These rules are set in table formats that enable users to alter parameters (i.e. objects and values). However, a new rule cannot be created until users obtain authority to use the SMC extension programming interface (API). This API is not free for public use and thereby restricts the SMC capabilities and extensions (Solibri 2007).

Jotne EDModelChecker (EDM): EDM is an object database that supports IFC-based BIM models. It also supports rule-checking activities using the EXPRESS language that writes IFC schema models. A model viewer can be created through EXPRESS-X that enables instance data to be mapped from one EXPRESS schema to another. EXPRESS-X also supports queries and textual reports. Users of EDM may develop their own extensions, which are supported by the EDM Model Server. EDM is an object-based database server that allows EDM to deal with large building models (Edmiston 2003).

FORNAX: This application has been developed by nova CITYNETS Pte. Ltd on top of the EDM Model Checker for the Singapore CORENET project. FORNAX is an object library written in C++ that derives new data and generates extended data for IFC models (Khemlani 2011, The Institution of Engineers, Singapore 2013). FORNAX objects carry rules for assessing themselves, providing good object-based modularity. The structure for the FORNAX platform is illustrated in Figure 3.8.

SMARTcodes: This is a new platform developed for the American ICC project. It provides methods for translating written language rules into computer code using a dictionary of domain-specific terms and semi-formal mapping methods. SMARTcodes also provide methods of accessing the relevant data in an IFC model and reporting on results. SMARTcodes have been developed by AEC3 and Digital Alchemy (Nawari 2013, 2012a).

The platforms described above outline how rules are created and communicated with BIM models. Most contain their own object database that enables IFC based BIM models to be extended. In addition, they emphasize rules involving value settings for specific objects (e.g. the width (values) for corridors (objects)). This presumes that users understand and incorporate their object libraries into their model designs before they commence code-checking activities. Moreover, many building regulations contain descriptive rather than numeric requirements. These make it difficult for design code-checking rules to assess building designs against descriptive requirements (Nawari 2012a). The above introduction provides a basic understanding of code-checking systems and underpins the next section which investigates the code-checking systems currently available.

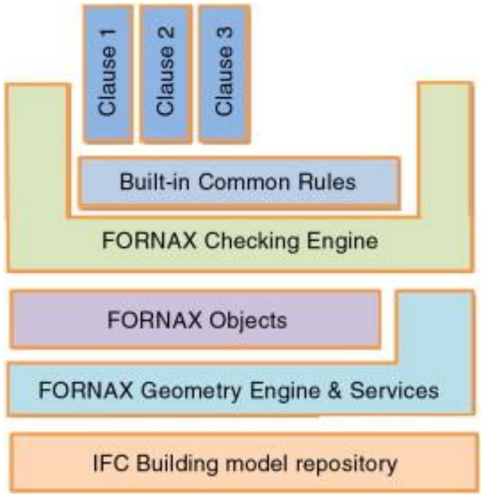


Figure 3.8 Structure of FORNAX platform

Source: (Eastman, C. et al. 2009: 1019)

3.6 Survey of BIM-enabled code-checking systems

Several studies have developed code-checking related projects for different national building regulations. These studies agree that code-checking technology is an effective means of enabling regulatory systems and certification processes to be reformed (Abrantes 2010, Rogers 2012). However, factors affecting the development of code-checking systems are complex. These require BIM standards and guidelines, including BIM model and data exchange, interpretation of various regulations, and education and training to ensure that building models are appropriately constructed to support code-checking assessments (buildingSMART Australasia 2012). BIM-enabled code-checking has the potential to achieve a higher level of compliance with fewer compromises of code and standards than manual methods(Fenves, S. J. et al. 1995, Nawari 2012a). Several prototypes have been developed but most remain experimental. The following sections discuss code-checking systems including their framework, target regulations, format of BIM models and programming techniques.

3.6.1 CORENET – Singapore

The concept of computer-aided code-checking for the Singaporean building industry was conceived in 1982. However, it was not undertaken until 1995. At this time, the Construction and Real Estate NETwork (CORENET) project was initiated by the Ministry of National Development, with the Building and Construction Authority as the lead implementing agency. In 2000 CORENET began to adopt IFC-based schema data. This system comprises four strands: e-Information, e-Submission, e-Catalogue and e-Plan Check. e-Information provides an advisory central repository of building and construction-related information (e.g. building codes, regulations and standards) for various industry professionals. e-Submission allows developers to submit building designs over the internet using 2D drawings or BIM models. e-Catalogue provides information about building materials, products, labour and services to assist stakeholders make design decisions, drawings, specifications and purchases. This study focuses on e-Plan Check and the manner in which it deals with code checks on building plans (IBP) and code compliance on building services (IBS). The former deals with building control, barrier free access, fire code, environmental health, household, public housing and vehicle parking. The latter covers electrical, fire alarm, fire sprinkler, rising main and fire hydrant, ventilation, sanitary, plumbing and drainage, surface water drainage, gas pipe and water services systems. CORENET e-Plan Check highlights the interoperability of IFC-based BIM models. However, mapping IFC Schema according to the needs of code-checking rules is problematic. This is due to a fact that model properties cannot completely support code-checking rules and e-Plan Check has thus not yet been implemented. The ways e-Plan Check is used to support code-checking activities are described below.

The Singaporean code-checking project, CORENET is the earliest code-checking system based on BIM. It deals with most building regulations including building plans and services. Significantly, more than 3.54 million online code-checking submissions have been made through CORENET (The Institution of Engineers, Singapore 2013). CORENET is seen as a foundation underpinning the code-checking systems described in the sections that follow. CORENET assesses 2D drawings and then uses the FORNAX platform to communicate checking rules and BIM model information. Despite ongoing attempts to implement performance-based checking extensions, the challenges of verifying data quality remain (Solihin, Wawan 2004). As e-Plan Check has not been implemented, CORENET currently provides users with electronic guidance and templates for BIM model creation and submissions. CORENET is unable to examine building designs in different stages of design (Ding et al. 2006).

3.6.2 HITOS (Norway)

The development of the ByggSok system in Norway was based on CORENET (Haraldsen et al., 2004). This is an e-Government system comprising three modules: an information system, a system for e-submission of building applications and a system for zoning proposals. This project is driven by the Norwegian Building and Construction industry and supported by Standards Norway and Norwegian buildingSMART. It uses IFC formats as the standard for BIM models. Work on the ByggSok system focusses on the issues of classification, terminology and standardising rule-checking in construction at an international level.

Building upon their e-PlanCheck pilot projects, Norwegian developers (Statsbygg) have experimented with multiple systems as part of their efforts to extend the use of IFC to the entire project lifecycle in support of their mandate that by 2010 all properties will use IFC based BIM (Sjøgren, 2007). The resulting systems have been piloted on real projects, with data being exchanged through a wide selection of software to suit the various stages / tasks of the project lifecycle. On the HITOS pilot, the code checking efforts have focused predominately on accessible design. Here the building model data are stored and accessed through EDM Model Server in IFC format. The accessibility rules are parameterised mapped to their associated building objects and executed using Solibri Model Checker's Constraint Set Manager. Solibri communicates directly with building model data in IFC format, but retrieves only the objects it needs – i.e. those mapped to the accessibility rules. The rules implemented to date focus predominantly on geometrical constraints and as such the objects and parameters are supported by the IFC data models produced by current BIM packages. The Statsbygg Solibri system does not support the enhancing of these data models or the export to IFC format, and so cannot currently be used for compliance checking of attributes not supported by the current BIM vendors. The Solibri Constraint Set Manager is implemented in java and ships with a library of built-in parameterised rules which can be configured by adjusting the parameters. New rules, however, must be custom made in collaboration with the Solibri software developers and as such are not easily adapted for other software. Solibri has the benefit of a powerful 3D modelling engine which, in combination with the ability to directly read IFC files, allows for clear visual reporting of rule infringements for users. Solibri's built-in rule library contains rules for validating a data model prior to rule checking which is useful.

Figure 3.9 illustrates an overview of the HITOS project. This shows that two rule engines, dRofus and SMC, have been adopted to assess IFC-based BIM models against spatial requirements and accessibility rules respectively.

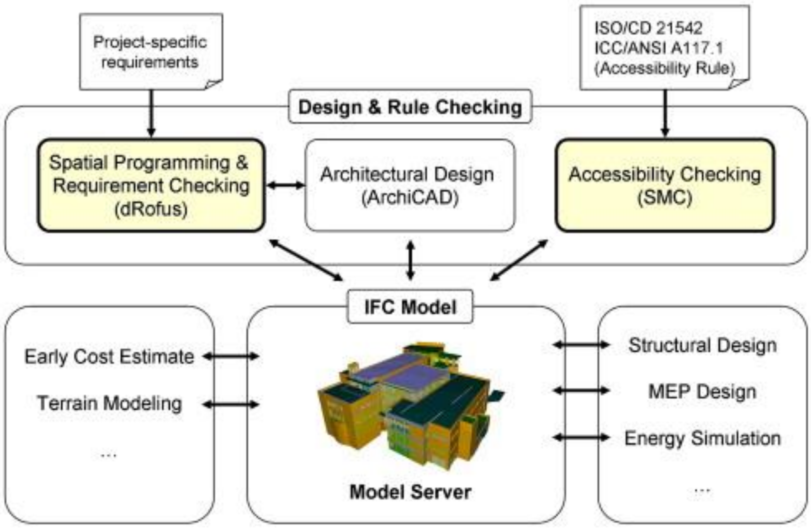


Figure 3.9 Process overview of the rule checking in the HITOS Project.

Source: (Eastman, C. et al. 2009: 1020)

3.6.3 DesignCheck (Australia)

Both the SMC and the EDM were considered as possible platforms for automated code checking in Australia (Ding et al. 2006, 2004)The work was undertaken by Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the University of Sydney and was funded by Australia's Cooperative Research Centre for Construction Innovation (CRC-CI). EDM was eventually selected and the resulting automated code checking system – DesignCheck was trialled by the construction industry in Australia (Eastman et al., 2009). DesignCheck uses object-based rules, encoded using EDM. Building data models, in IFC format, are imported into the EDM database and transformed into the Design Check internal model. The Design Check model includes building code specific information not currently implemented by BIM vendors. A mapping schema, written in ExpressX translates the building data model from IFC format into the DesignCheck schema. The strategy is similar to that of e-PlanCheck in Singapore; however, DesignCheck is able to check for compliance at various stages in the design process as it has a rule schema for early and detailed design stages as well as for specifications. It is therefore targeted at Architects rather than just Building Control certifiers (Ding et al., 2006). DesignCheck does not allow users to view 3D models and all reports are text based.

3.6.4 SMARTcodes projects (USA)

Similar work on code-checking began in the United States around 2000, with the initial emphasis on health, safety and welfare. A major driver of BIM and validation of BIM models in the United States is the US General Services Administration (GSA). The GSA issued BIM-guidelines in late 2006 (GSA, 2006) and in 2007 proposed that all planners seeking funding for their spatial planning projects would need to produce BIM models for validation in an open standard (GSA, 2007). The aptly named SMARTcodes is a project driven by the International Code Council, in conjunction with AEC3 and Digital Alchemy. This project focused largely on addressing the problem of transforming paper-based codes (of which there are thousands) into machine-interpretable rules. This is generally a lengthy process requiring much iteration between Building Code officials and software developers (Figure 3.10). In order to streamline this process the SmartCodes project developed a methodology for applying tags to electronic copies of Building Codes using a ‘tag dictionary’, or ontology (Nawari 2013). The rules are then automatically extracted, following a strict mathematical pattern, into an IFC constraints schema. The resulting IFC constraints schema is mapped to the IFC building data model via a tag dictionary. The rules can currently be executed using either Solibri Model Checker, or AEC3 XABIO. The SmartCodes project does not support building code specific information that is not currently implemented by BIM vendors (Eastman et al. 2009).

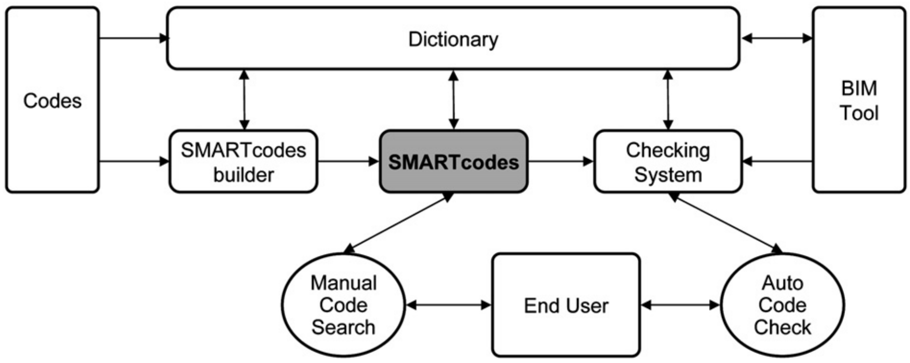


Figure 3.10 Framework of model checking system based on SMARTcodes.

Source: (Eastman, C. et al. 2009: 1026)

3.6.5 LicA (Portugal)

LicA checks domestic water systems against the main Portuguese regulations. It uses the Scratch software to develop its platform including the code checking algorithms and its graphical user interface (GUI) (Martins and Monteiro 2013). This system comprises three main components: LicA, LicAXML, LiCAD. The LicA database is the main component in the toolset (Figure 3.11). It contains a set of tables that describe the domestic water system (its physical components and their relevant properties) and modules for hydraulic calculation, code checking and reporting. All of these items are contained in a single SQL database. LicAXML allows for the exchange of information between the stakeholders and the entity that performs the code checking. The design information of a BIM model is performed using the XML standard format. LiCAD not only edits and browses functions, it allows stakeholders to check the compliance of domestic water system designs with national regulations before certification by the governing bodies. This system represents a combination of 2D (plans, elevations, etc.) and 3D (projects, perspectives, etc.) and other construction documents (bills of quantities, code checking reports, etc.). The checking results are shown in text format although this software also provides 3D modelling functions.

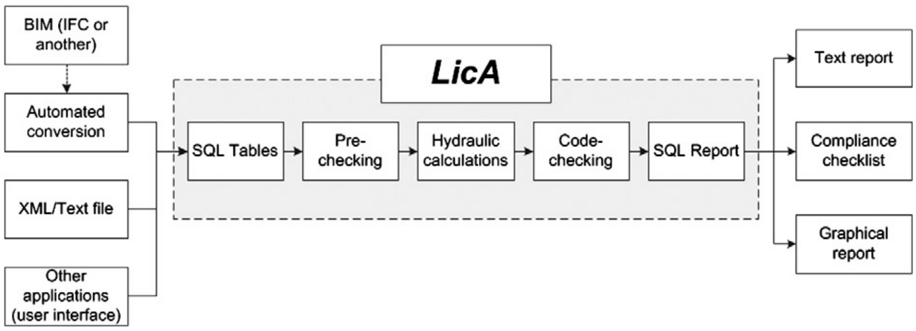


Figure 3.11 LicA's conceptual architecture — database, input and output elements

Source: (Martins and Monteiro 2013: 15)

3.6.6 ACCBEP (Canada)

The purpose of the ACCBEP (automated code checker of building envelope performance) system is specifically to check building envelope design for compliance with building codes. The framework of this approach comprises four components: Extended Building Information Model (EBIM), Extended Building Code (EBC), Rules Engine and Assessment Results (Figure 3.12). XML has been adopted as the representative format of EBIM due to its flexible characteristics. The XML-based objects are generated from an incorporation of the widely-recognized representatives of BIM model – IFC (Industry Foundation Classes), IAI (International Alliance for Interoperability) or GDL (Geometric Description Language) into simulation tools such as Moist (US Department of Commerce 2011), 1D-Ham (Carl-Eric and Thomas 2000), Wufi Pro (WUFI-ORNL/IBP n.d.) and Moisture-Expert (Karagiozis 2001). EBC consists of an electronic version of the building code and XML-based decision tables, which express the logic of the building code. The core algorithm of the Rule Engine (Rete algorithm) treats EBIM and EBC as nodes to be checked and then the matching results are obtained. Finally, the Assessment Results reports the compliance checking results, the related design regulations, reference indices as well as advice on decision-making to stakeholders.

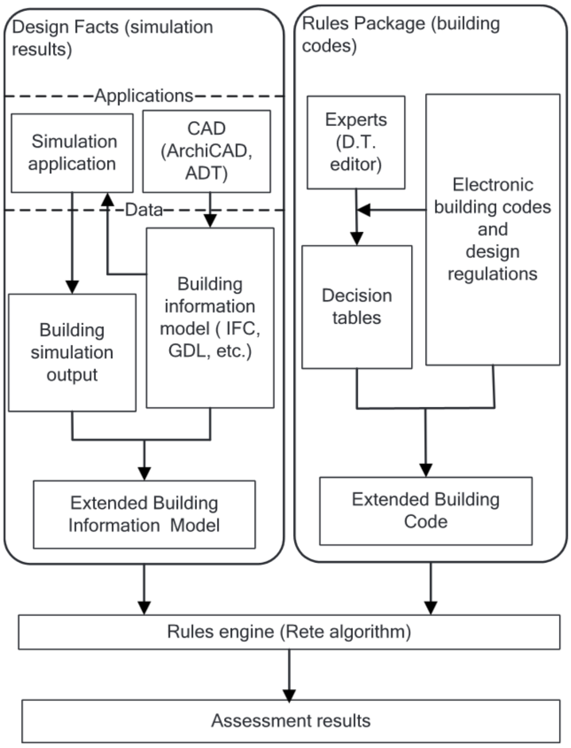


Figure 3.12 Framework of the ACCBEP

Source: (Tan et al. 2010: 204)

3.6.7 GTPPM (Korea)

This study focuses on checking compliance with building codes regarding fire resistance. The checking process is divided into two parts: a re-interpretation of codes for automated checking and an extraction of building information from BIM models. These two parts are then combined as a system – Georgia Tech Process to Product Modeling (GTPPM) – to facilitate automated checking. The authors categorized codes into five topics: Egress Way, Material/Capability, Principles of Evacuation, Evacuation Stairways and Fire Protection Partitions. These were established as criteria in the code interpreter. The information extracted from BIM models using IFC is represented in 2D format and then checked by a code interpreter. The checking results are then shown in a text report (Jeong, J. and Lee, G. 2010).

3.6.8 InSightBIM-Evacuation (Korea)

InSightBIM-Evacuation, a BIM-based code-checking system, has been developed within the Korean building regulatory context. This system enables high-rise and complex building designs to be assessed against evacuation regulations (emphasizing fire compartments and accessibilities). InSightBIM-Evacuation works on an independent platform (written by Visual Studio 2008) comprising three components: BIM model view, Quality check for property information and evacuation regulation check (Figure 3.13). It incorporates two external third-party programs, IFC Engine DLL (RDF n.d.) and Open Cascade (Anon. n.d.). The IFC Engine DLL is a commercial STEP-based toolbox that enables Step-based (including all IFC versions) BIM models to be imported, exported and edited. InSightBIM-Evacuation uses the IFC Engine DLL as a parser to simplify BIM models data and to communicate BIM data with the (InSightBIM-Evacuation) rule engine. Open Casade is a simulation tool that is able to exchange and visualize CAD model data in a cross-platform environment. InSightBIM-Evacuation uses Open Casade as a model viewer to represent physical geometry.

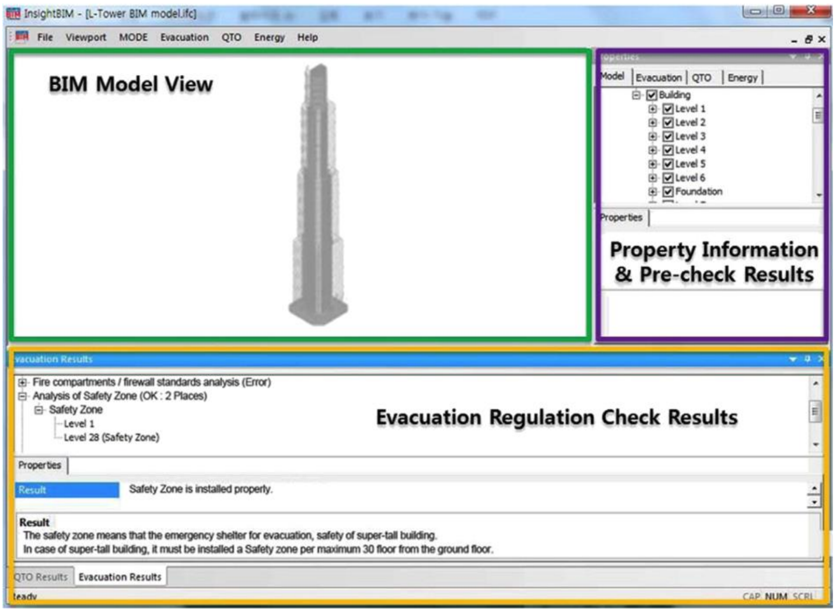


Figure 3.13 Components of InSightBIM-Evacuation

Source: (Choi, Jungsik et al. 2013: 39)

InSightBIM-Evacuation only allows IFC-based BIM models to be assessed. However pre-defined property sets (Pset) within IFC schema cannot provide all the information required for evacuation assessment. The ways to accommodate properties for assessment activities require stakeholders to use a specific object library (Korea BIM Standard, KBIMS) to create BIM models. In addition, stakeholders need to add additional properties to BIM models to support assessment as shown in Table 3.5. For example, they need to define the ‘Department’ of space property and ‘Combustible’ for wall properties. If stakeholders do not identify all the properties required, InSightBIM-Evacuation has a ‘quality check’ to inform stakeholders that all required properties are identified before commencing evacuation assessments (Choi, Jungsik et al. 2013).

Table 3.5 Property definitions of evacuation regulations

List	Property definition
Analysis of fire compartments and firewalls	• Defining a "*Department*" of space property as a "*Fire Partition*" • Defining a "*Combustible*" of main structure Pset as a "*False*" • Defining a "*Combustible*" of "*Pset_WallCommon*" surrounding the fire compartments, as "*False*"
Analysis of evacuation safety zones	• Defining a "*FireExit*" of "*Pset_SpaceFireSafetyRequirements*" as "*True*" • Defining a "*Department*" of space property as a "*Safety Zone*"
Analysis of escape stairs and exit routes	• Defining the escape stairs' "*FireExit*" property of "*Pset_StairCommon*" of IfcStair as a "*True*" • Defining the outward exit's "*FireExit*" property and "*IsExternal*" of "*Pset_DoorCommon*" of IfcDoor as a "*True*" • Defining "*IsCombustible*" of "*Pset_FireRatingProperties*" of IfcBuilding as "*True*"
Analysis of emergency elevator	• Defining "*FireExit*" of "*Pset_TransportElementCommon*" as "*True*"

Source: (Choi, Jungsik et al. 2013: 46)

The model used for examinations was not obtained from practical projects. A purpose-built BIM model (using Revit) was created solely for the purpose of examination. The ways to verify InSightBIM-Evacuation require reference to be made to a real building design. Therefore the BIM model contains all the properties required for evacuation assessment. The assessment results enable instances of non-compliance to be highlighted visually (Figure 3.14) whilst the assessment reports are produced is not described.

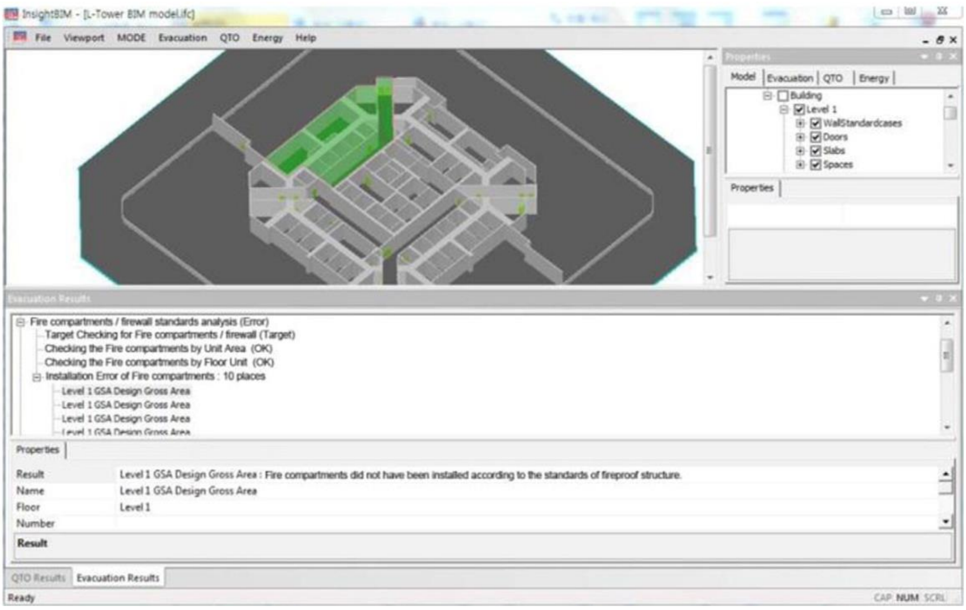


Figure 3.14 Results for checking fire compartment and firewall installation criteria

Source: (Choi, Jungsik et al. 2013: 47)

This study highlights the significance of regulation compliance for stakeholders during the design process. It enables IFC-based BIM models (exported by various vendors) to be assessed against evacuation regulations. In addition, it emphasizes the need for completeness of BIM properties for assessment. The necessary properties can be pre-checked through a 'quality check' and stakeholders can address the lack of properties of BIM models. However, this may result in additional workload for stakeholders. Although it clearly defines the required properties for assessment, stakeholders need abilities and knowledge to add required properties manually to BIM models for evacuation assessment. In addition to creating these new properties, attaching relevant properties to BIM models may also require that stakeholders understand building regulations. This system has identified the required properties for assessment while the ways to interpret the requirements of building regulations are not discussed. Moreover, this system does not allow stakeholders to revise model data directly when instances of non-compliance occur. The limitations discussed above may influence the uptake of InSightBIM-Evacuation in building industry (Choi, Jungsik et al. 2013).

3.6.9 BCAider & AutoAider (Australia)

BCAider is a knowledge-based code-checking system for Australia. This system was developed by CSIRO and was initially released for commercial use in 1991. It enables stakeholders and certifying authorities to check designs for BCA compliance in a consistent manner. The ways the BCAider checks designs requires users answer several questions (Figure 3.15).

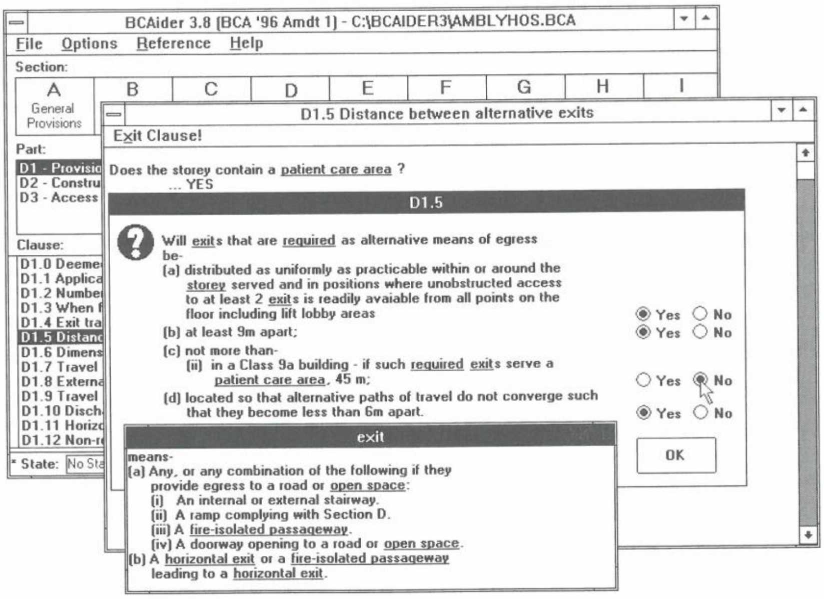


Figure 3.15 An example to process a building code

Source: (Sharpe 1991: 118)

The software that handles the interaction and display of this information is called AutoAider. AutoAider is an intelligent assistant to the design/drafting process. It observes a draftsperson's actions and immediately presents BCA information applicable to the current task. Using AutoAider, a stakeholder can view the text of relevant clauses or process them using BCAider (Sharpe 1991).

3.6.10 Comparison and conclusion

A comparison of the commonalities of these systems is shown in Table 3.6. This table provide a framework for reviewing code-checking systems and is composed of the following four key components: (Choi, Jungsik et al. 2013)

Informer: This application engages BIM models and reads information (such as size, distance, etc.) as the “Informer” component. Several studies have highlighted the creation of a component to extract the required information using IFC-based formats such as IFC, ifcXML or to integrate IFC models into a new digital schema (Tan et al. 2010, Yang and Li 2001). However, the IFC-based formats exported by different vendors may contain variations (Pazlar T 2008).

Ruler: This component defines the context of building codes in logical and readable ways that the attributes of BIM models can conform to. It involves an interpretation process from the semantic structure of each regulation to rule-based engines or parametric tables. This functions as a database to facilitate the Informer to interrogate required codes (Solihin, W. and Eastman, C. 2015).

Communicator: This works as a mediator between the Informer and the Ruler. It checks information provided by the Informer against the codes database of the Ruler, mapping whether it complies or not, and afterwards providing results to the Reporter (Eastman, C. et al. 2009).

Reporter: When the checking process finishes, the Reporter generates a report based on the results provided by the communicator in textual and/or visual formats (Ding et al. 2006, Eastman, C. et al. 2009).

Of particular relevance to this study is DesignCheck. This is the only system that allows BIM models to be assessed for compliance with the disabled access requirements of the National Building Codes of Australia (AS1428.1). Although DesignCheck demonstrated several benefits with regard to code compliance, some shortcomings still need to be addressed. For example, IFC model formats vary according to different software vendors. Some of these formats lack required information, which cannot support the BIM-CCS. Moreover, it only focuses on disabilities and does not display visualisations of checking reports.

Table 3.6 Comparison between code-checking systems

	Singapore:CORENET	**Norway: Statsbygg**	**United States: ICC**	**Australia: DesignCheck**	**Portugal: LicA**	**Canada: ACCBEP**	**Korea: GTPPM**	**Korea: InSightBIM-Evacuation**	**BCAider & AutoAider**
Target Rules	Building code	Accessibility	Building code	Disabilities (AS1428.1)	Water system	Building envelope	Fire resistance	Evacuation	Entire BCA codes
Checking Platform	FORNAX	SMC	DA's SMARTcodes for SMC, XABIO	EDM	LicA	Rule Engine (Rete Algorithm)	Checking engine	SMC	none
Informer (BIM models)									
Using IFC-based model	YES	YES	YES	YES	YES	YES	YES	YES	No
Add new properties Using enhanced objects	YES, called FORNAX	YES, Adding geometry data	YES, using DA's SMARTcodes for SMC, XABIO	YES, using internal model schema to define objects and properties	NO	NO	YES	YES	–
Extract IFC properties to new format	NO	NO	NO	NO	YES, using LicAXML to create XML-based model	YES, XML-based model	NO	NO	–
Ruler (building codes)									
Translating by programmer	YES	YES		YES	YES	YES	YES	YES	No
Employs predicate logic or similar derivation process	YES		YES						
Rules Coded in	Computer code	Parametric Tables	SMARTcode builder	Rule-based language	XML-based parametric Tables	XML based Decision Tables	Computer code	Rule-based language	Interactive descriptions
Communicator (checking execution)									
Building model validation to verify minimum model requirements for checking		YES	YES	Runs the chosen rule set against the model to identify areas with insufficient information	YES	YES			No
Report Generator (assessment results)									
Graphical reporting	YES	YES	YES	Graphic display of the check results; 3D visualization not linked.	NO	YES	NO	YES	No
Textual reference	YES	NO	DA's SMARTcode for SMC, XABIO	YES	YES	YES	YES	YES	Yes

Adapted from: (Eastman, C. et al. 2009, Tan et al. 2010, Abrantes 2010, Jeong, J. and Lee, G. 2010)

3.7 Australian strategies for BIM-CCS implementation

The concept of BIM-enabled code-checking has been recognised by buildingSMART Australasia (2012). They agree that the BIM-based analysis used to monitor regulative compliance requires the integrated involvement of many stakeholders including scientific communities, regulatory authorities and production manufacturers. Furthermore, buildingSMART advocates a strategic plan for regulatory reform through the establishment of building approval systems using BIM for the Australian built environment sectors. The National Building Information Modelling Initiative (NBI) Report (buildingSMART Australasia 2012) notes that project developers and certifying authorities will need guidance on assessing BIM-based projects for compliance within a five-year (2012-2017) national BIM initiative implementation plan (Figure 3.16). This plan is arranged in three sequential phases:

As traditional designs are notorious for repetitions and fragmentation, the first stage is to coordinate information and activities between relevant industrial sectors using IT technology such as BIM. The Australian government may need maximum involvement to encourage and regulate the source parties on establishing building-related information without duplicated efforts. This may include protocols for BIM, geographic information systems (GIS) and information delivery mechanisms (such as web services). Moreover, all these data need to be interoperable and exchangeable. This can significantly reduce the administrative burdens faced by project developers who currently collect information transferred manually from various sources.

The next stage is to establish a model-based building regulatory compliance process. Australia has set itself an objective of being a world-leading digital economy by 2020 (Hampson and Brandon 2004, Steven Goh 2007). This requires an Australian building regulatory system evolving to a model-based certifying system. This will also enable Australia to enhance collaboration with New Zealand as New Zealand has set a similar agenda for their regulatory reforms.

The last stage is to develop a strategic plan for the transition of the Australian regulatory system and compliance mechanisms to model-based performance-based systems. The priority is to develop an implementation plan so that building sectors can work on a collaborative platform for approval and compliance activities. When all affected Australian building-related sectors collaborate in a digital manner, the eventual move to the model-based approval and compliance system will be achieved. buildingSMART Australasia proposes that e-Planning Australia has the potential to be undertaken as a collaborative platform for design compliance.

At present, the Australian construction industry remains at the first stage. Although BIM technology has been increasingly incorporated in the design process, users' BIM knowledge and capabilities need to be enhanced to reach an improved BIM maturity level (Succar 2009, Succar et al. 2012). This can enhance the interoperability of BIM models that created from different disciplines. This then can be the foundation underpinning the second stage establishing the object-oriented certifying systems.

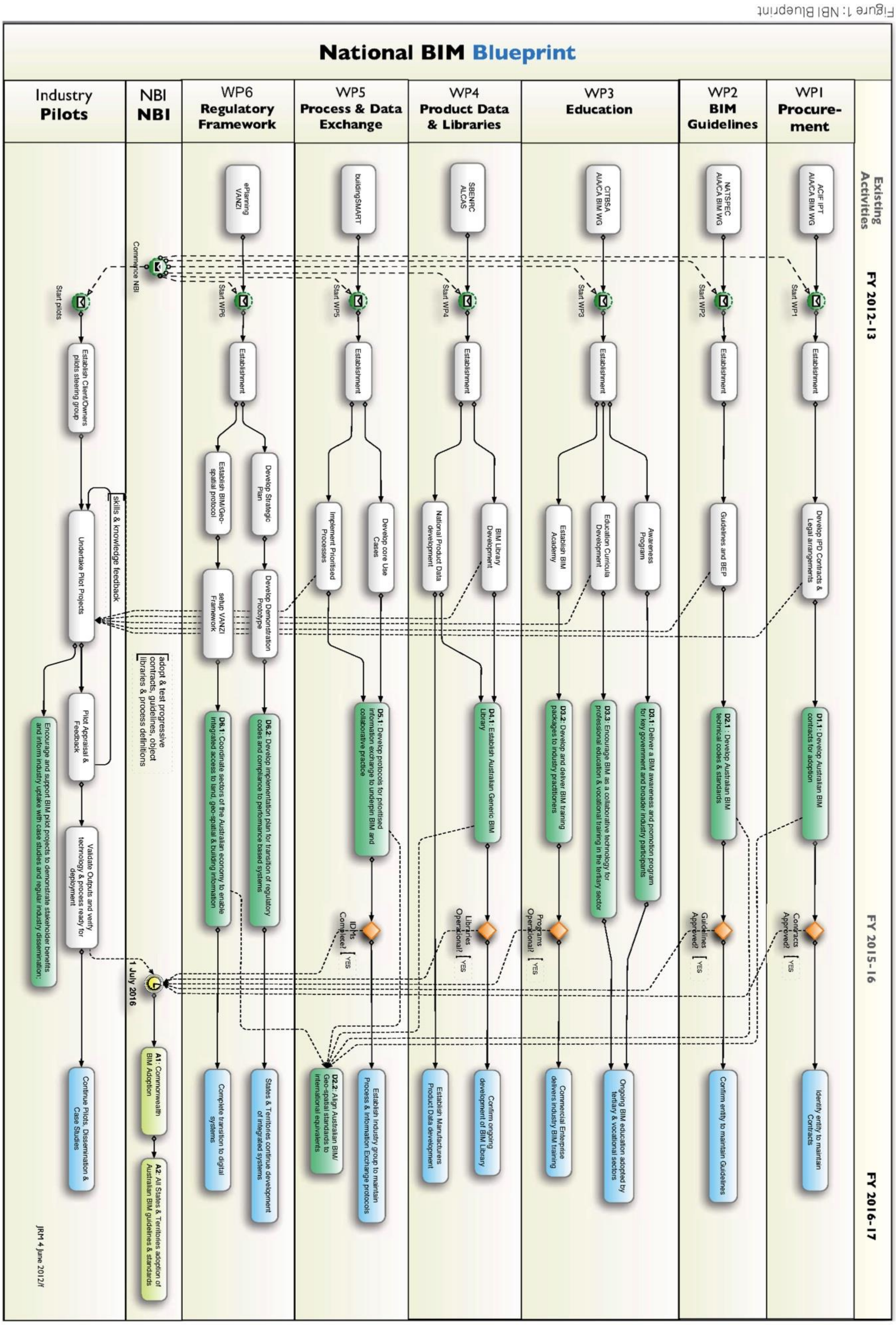


Figure 3.16 National BIM Blueprint

Source: (buildingSMART Australasia 2012: 3)

3.8 Summary

This chapter has investigated and discussed BIM and BIM-CCS technologies. BIM has been shown to improve performance and efficiency, communication and collaboration for project stakeholders. Although IFC schemas are recognized as effective ways of communicating and coordinating BIM models from various sources, several issues still exist (e.g. incomplete objects or missing parameters when importing and/or exporting models). However these defects do not invalidate the merits of BIM. BIM can be extended for various purposes including code compliance checking. Nine code-checking systems (CORENET, HITOS, SMC accessibility checking, DesignCheck, SMARTcodes projects, LicA, ACCBEP, GTPPM, InSightBIM-Evacuation and BCAider &AutoAider) have been investigated in terms of their model formats, rule settings, rule executions and reporting forms. Most BIM-CCSs support IFC-based BIM models while some studies have shown that IFC schemas are not able to be completely imported and/or exported. Four rule engines (SMC, EDM, FORNAX and SMARTcodes) were reviewed. These provide developers with platforms in which they can create and execute rules. They emphasize rules in the scope of dimensional measurements such as accessibility and space measurements. However, creating code-checking rules in these platforms is challenging where building clauses are descriptive or have open-ended requirements. The survey of these nine code-checking systems has provided a foundation for developing the *Ignis* structure for this study. Although BIM and BIM extensions are not widely adopted in the Australian construction industry, this study demonstrates the potential for connecting BIM and code compliance for project stakeholders. Through the investigation of BIM and its extensions, several key issues emerge from this chapter.

Key Issues

K3.1 BIM technology has not been broadly adopted in the design process by the Australian construction industry.

K3.2 There are few existing tools that enable building designs to be checked for compliance with the building regulations during the design process.

K3.3 Architects have high interests at code-checking tools.

K3.4 Most code-checking systems have not been implemented in the construction industry.

K3.5 Most -checking systems relate to specific and limited building regulations such as accessibility.

K3.6 The development of BIM-CCS is challenging and may require users to perform additional work (i.e. manually add parameters).

K3.7 Visual reports improve users understanding compared to the textual reports.

These issues raise the following questions about the development and implementation of code-checking systems.

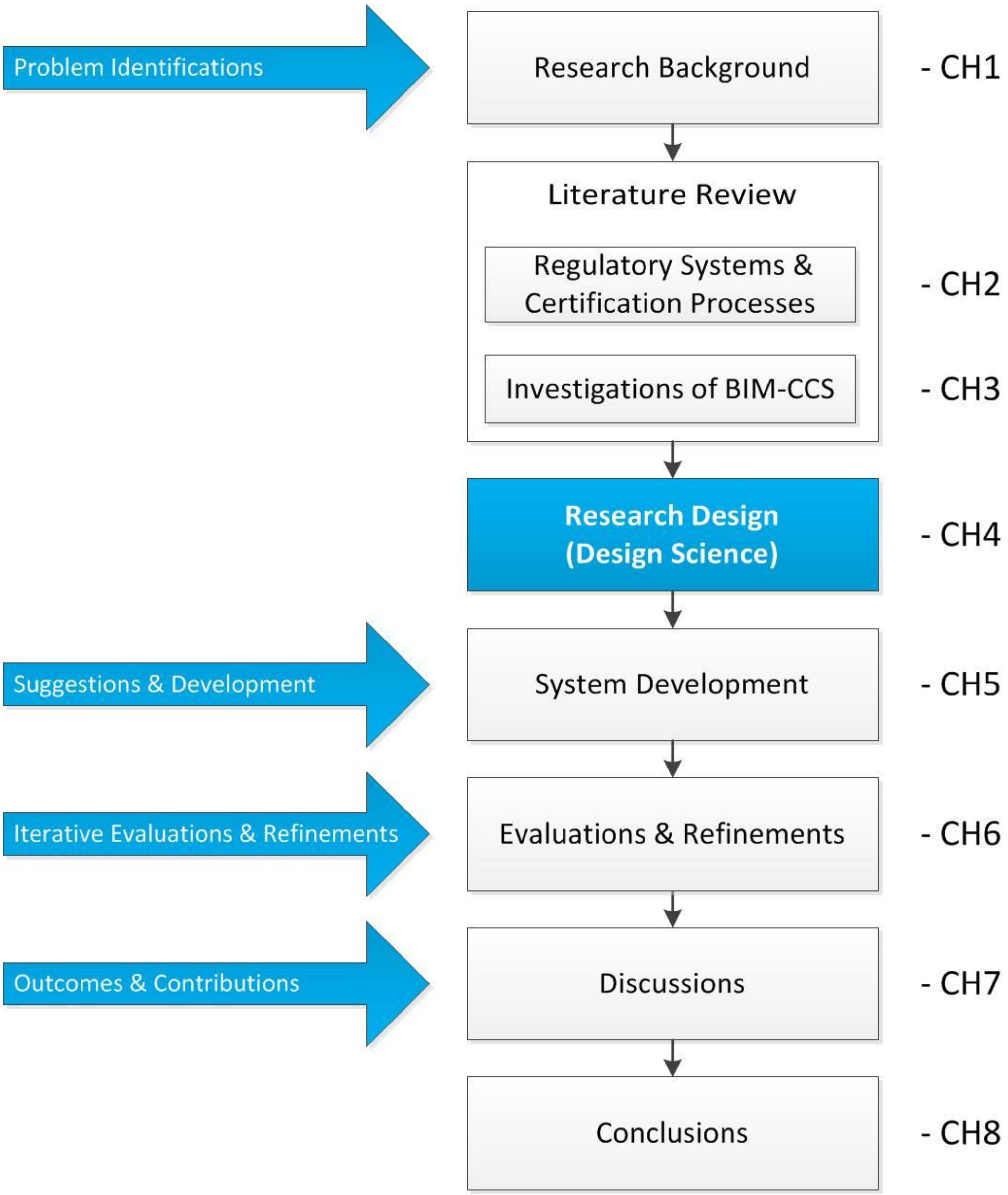
Research Questions

Q3.1 How can BIM (and BIM extensions) be used to check designs for compliance against the BCA during the design process?

Q3.2 How can users' efforts in code-checking be reduced?

Q3.3 How can users' understanding of code-checking results be improved?

4 RESEARCH DESIGN AND METHODOLOGY



4.1 Introduction

This chapter explores research approaches for creating *Ignis* that mitigates design compliance issues during the design process. It assists in clarifying the research processes adopted for this study and in justifying the research methods. These have enabled *Ignis* to be developed in a systematic manner.

Several developed BIM-CCSs have been surveyed in section 3.6 of Chapter 3 (at page 44). Despite the fact that few of them have been implemented, the concept of using BIM-CCS to solve compliance issues is practical and has been validated. However, factors effecting the development of BIM-CCS are complex. There are several questions that arise in this context. How can BCA clauses and BIM technologies inform the development of BIM-CCSs? What challenges are there within the BIM-CCS development that stakeholders need to address? Significantly, what actions are needed to address these challenges? The following research questions, raised in Chapter 2 and 3, provide the setting for this study.

Q2.1 How can technology assist in assessing designs for compliance with building regulations during the design process?

Q2.2 What can be done to assist in interpreting the BCA in a consistent manner?

Q3.1 How can BIM (and BIM extensions) be used to check designs for compliance against the BCA during the design process?

Q3.2 How can users' efforts in code-checking be reduced?

Q3.3 How can users' understanding of code-checking results be improved?

These questions assist to clarify what the design compliance issues are within the Australian construction industry, and how BIM extensions (i.e. BIM-CCS) can assist project stakeholders to deal with design compliance issues during the design process. These issues include fragmented building information between stakeholders, repeated rectification works between professionals and, significantly, the inconsistent certification results provided by different certifiers.

To answer these questions, this study has focused on the ways of developing a BIM-CCS within the Australian regulatory context. Several challenges were encountered during the development of the BIM-CCS. Researchers needed to propose and verify solutions to these challenges. Collectively, these challenges and solutions contributed knowledge about BIM-CCS within the Australian regulatory context. A BIM-CCS can be seen as a purpose-based artefact. The ways of creating artefacts can be studied in various scientific domains (e.g. social science and formal science). Design science has found favour as an effective means of understanding how people create artefacts to solve practical problems. Project stakeholders can use BIM-CCS as solutions for design compliance issues in practice. Design science highlights that the knowledge and theory can be produced from the artefact development process (Hevner, A. and Chatterjee 2010, March and Smith, G. F. 1995).

This chapter firstly describes the research aims and objectives that were constructed to address the aforementioned research questions. They provide an understanding of the factors affecting the development of the BIM-CCS. This is then followed by a review of relevant research philosophies and research methodologies in Section 4.3 and Section 4.4 separately. Section 4.5 provides a discussion of the research techniques used to accommodate the BCA, BIM information, and the ways to evaluate the BIM-CCS. The evaluation criteria for evaluation process are discussed in Section 4.6. A summary of how the BIM-CCS was designed is provided Section 4.7.

4.2 Research aim and objectives

The questions listed in Section 4.1 are encapsulated in the aim of this research (Section 1.6, page 7) which is to develop a proof of concept BIM-CCS that enables building designs to be checked for compliance with the BCA. This study seeks to provide a mechanism for a BIM-CCS prototype to generate code-checking results. *Ignis* is a BIM-CCS created for this study specific to the Australian construction industry. It can check commercial buildings whether comply with Section C Fire Resistance of the BCA. This study has applied a Design Science methodology to the *Ignis* development. Design Science has been widely used in Information System (IS) research because it can extend abilities for stakeholders by creating innovative artefacts (Hevner, von A. R. et al. 2004). It significantly emphasizes iterative activities in development and evaluation of the artifact (March and Smith, G. F. 1995). The following research objectives that underpin the aim of this study are proposed in accordance with Design Science principles.

Obj 1. To develop a structure for *Ignis* specific to Section C Fire Resistance of the BCA for commercial buildings.

> This study investigated nine BIM-CCSs at Section 3.6 (page 44). Most BIM-CCSs comprise four components: **rulers, informers, report generators and communicators.** These components informed this study, assisting the development of the structure for *Ignis*. Different techniques were used to build each component.
>
> The **ruler** highlighted the interpretation process of BCA codes. Several code clauses contain cross references and open-ended conditions, which complicates the interpretation works. The ways of interpreting fire-resistance codes to inform the design of **rulers** usually uses semantic analysis methods. It is necessary to determine appropriate semantic analysis methods that accommodate the characteristics of the BCA clauses. Furthermore, techniques for creating computerized rules were varied (e.g. decision-tables and hard coded rules). Semantic analysis results may assist in determining the programming techniques.
>
> The **informer** used BIM parameters but these did not fully support code-checking activities and can be mitigated by additional activities (e.g. manual inputs and additional calculations). **Rulers** need to accommodate complex requirements and it is not always possible to devise BIM parameters that completely align with them. In

addition, when transferring BIM models between different software packages it is possible that some parameters or geometries may be lost. Additional work may be required to solve these issues. For example, some BIM-CCSs may require users to add parameters to model elements whilst others require users to incorporate purpose-based object libraries into model designs.

The **report generator** facilitates the different ways assessment results are presented. This included visualizations, text-based reports or a combination of both these approaches. A key requirement was to present reports in a comprehensible manner, considering the context of the Australian construction industry, the certification system in Australia, and to take advantage of the inherent features of BIM.

The last component, the **communicator**, linked the informer, ruler and report generator. It needed to be able to obtain identified BIM parameters, assess whether they complied with each rule's requirements and then communicate results to the report generator. In addition, the platform may need to generate visualizations of BIM models.

Obj 2. To enable an *Ignis* prototype to perform effective code-checking activities.

This objective relates to the programming effort required to build the *Ignis* prototype, as well as an evaluation of the effectiveness of the code-checking activities. External assistance (i.e. software programming skills) was employed to build the *Ignis* prototype. Identifying appropriate programmers was therefore an issue. The one chosen had BIM knowledge and experience in developing BIM extensions. This provided a foundation for communicating the requirements of *Ignis*. To facilitate communication, the researcher prepared documents specifying the *Ignis* structure. These documents defined the processes for code-checking rules, identified the required BIM parameters and outlined how to present reports of results. Throughout the development of *Ignis*, all design and programming works, particularly the ways the code-checking rules operated, needed to be verified. During the programming process, a variety of testing models were used for self-evaluation. Having created the *Ignis* prototype, further evaluations were conducted with regulatory experts (e.g. accredited certifiers). This evaluation explored how rule designs were processed by *Ignis*, what BIM parameters the rules connected with, and how the results reports were presented. The evaluation criteria were based on Design Science-related studies. These enabled the development and testing of effective code-checking activities.

Obj 3. To investigate the manner in which project stakeholders use *Ignis* to facilitate design activities during the design process.

> This objective explored the potential of *Ignis* to inform the development of compliant building designs. It engaged project stakeholders in evaluation activities by demonstrating *Ignis* to them and a series of questions according to evaluation framework have been asked. The participants can have opportunities to operate *Ignis* during the demonstration. They therefore experienced how *Ignis* worked and what output they could obtain to improve and revise their building designs. Their feedback was collected and analysed.

These objectives identify the data required to support the research aim of this study. Issues and possible approaches to solve these issues have been discussed. This chapter then describes the research methodologies and methods by which these objectives have been addressed in the following sections.

4.3 Research Philosophies

All research projects need to consider philosophical implications including ontological, epistemological methodological and axiological perspectives, whether explicitly or not, as fundamental bases of the socially constructed realities for their research (Berger and Luckmann 1966, Searle 1995). This assists researchers to understand how and what they can learn from the research activities. These philosophical perspectives can be understood as (Kuhn 1962, Shapere 1964):

- Ontology is the knowledge that describes the nature of reality;
- Epistemology is the ways to explore the nature of knowledge;
- Methodology is the process to guide the study, and
- Axiology is the study of values.

Positivism (nature science) and interpretivism (social science) are the two well-known research approaches having contrasting ontological and epistemological assumptions (Guba et al. 1994). Positivists assume that theories or meaning reside in the world (Laudan 1996). They intend to gain ideas or knowledge through observations and measure objective realities. They normally set reductionist goals and thereby may reduce the ideas into a small, discrete set of ideas. It begins with theories, collects data, and then revises and deals with additional examinations (Lin 1998). Quantitative methods are usually used to evaluate, verify and refine the theories that they have observed (Creswell 2013).

Alternatively, interpretivists consider the reality is constructed intersubjectively through the meanings and understandings developed socially and experientially (Walsham 1995). Individuals cannot separate themselves from what they know. Interpretivists assume investigator and the object of investigation are linked, and thereby seek understandings for who we are and how we understand the world. This is a central part of how individuals understand themselves, others and the world. They usually adopt qualitative methods construct meanings and /or meaningful realities between the researchers and those whom they interact with (Walsham 1995).

Differentiating from the positivism and interpretivism, Gregg et al. (2001) has proposed a meta-level assumption of design science (that is also pre-termed as the socio-technologist approach). Table 4.1 summarises the philosophical assumption between these three research perspectives. Design science is unique to the world. Its ontology, epistemology and axiology are not derivable from the others and are discussed below individually. The methodology shapes the ways to develop *Ignis* in a systematic way. This is then further explored and discussed in section 4.4 (at page 68).

Table 4.1 Philosophical assumptions between the three research perspectives

Basic Beliefs	**Research perspective**		
	Positivist	Interpretivist	Design Science
Ontology • What is the nature of reality?	A single reality. Knowable, probabilistic	Multiple socially constructed realities	Known context with multiple socially and technologically created realities
Epistemology • What is the nature of knowledge?	Objectivity is important; researcher manipulates and observes in dispassionate objective manner	Interactive link between researcher and participants; values are made explicit; created findings	Objective/Interactive; Researcher creates the context and incorporates values that are deemed important
Methodology • What is the approach for obtaining the desired knowledge and understanding?	Quantitative (primarily); interventionist; decontextualized	Qualitative (primarily); hemeneutical; dialectical; contextual factors are described	Developmental (primarily); focus on technological augmentations to social and individual factors
Axiology • What is of value?	Truth: universal and beautiful; prediction	Understanding: situated and description	Control; creation; progress (i.e. improvement); understanding

Source: (Gregg et al. 2001: 172, Hevner, A. and Chatterjee 2010: 17)

4.3.1 Ontological level

An obvious differentiation of the positivist view is that it emphasizes a single, composite socio-technical system, while design science researchers believe that there are multiple constructed realities (Petter et al. 2010). However, this is similar but not the same as the interpretivist view (that there are multiple socially constructed realities). Design science researchers seek to change the state-of-the-world or solve intended problems by bringing novel artefacts into reality, highlighting multiple socially and technologically created realities (Petter et al. 2010).

This study has explored real-world problems focusing on code compliances for building designs in the Australian construction industry. It focuses on the inabilities of stakeholders to incorporate code compliance activities of building designs in the design process. The use of the BIM-CCS (as the artefact) is proposed to solve these design compliance issues. When the BIM-CCS is incorporated in the design process, the constructed relationship between project stakeholders and the BIM-CCS can be investigated.

4.3.2 Epistemological level

At the epistemological level, when design science researchers establish that a piece of information is factual, they may further explore the meaning of the information based on the process of development. A created artefact may have several components that interact with each other and then produce results. These interactions relate to the information and/or knowledge that design science researchers are interested in.

Simon (1996) used the term ‘science of the artificial’ (also known as design science) and gave an explanation that design science is ‘a body of knowledge about artificial (manmade) objects and phenomena designed to meet certain desired goals.’ (1996: 252)

The BIM-CCS created in this study is also constituted of components (described in the next chapter) that interact to produce code-checking results for project stakeholders. Code-checking activities may require specific objects or conditions for each building code. The way to undergo code-checking activities effectively enables knowledge to be explored through the development process. The design science researcher is thus seen as the pragmatist that investigates ways to change, improve or even create specific behaviour or phenomenon in the world (James 1995, Peirce 1974).

4.3.3 Axiological level

The value inherent within design science research is the creative manipulation and control of the environment. Gregor and Henver (2013) point out that the value of design science research can be a practical or functional addition to an area or body of knowledge, even as a partial theory or an incomplete theory. It may provide a contribution or knowledge as basis for further investigations.

This study has created a BIM-CCS specific to Section C Fire Resistance of the BCA. This is an innovative work for the Australian construction industry in the fire resistance area. Although only part of the BCA has been investigated, the knowledge gained from Section C provides a foundation and applicability for the future development of other sections of the BCA. Design science is a method that fits the purpose of this study within the information systems area. “Design Science is the scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest” (Johannesson and Perjons 2014: 7). Design science focuses on knowledge and theories generated from the process of creating purpose-based artefacts. Through the use of design science, the ways to design BIM-CCSs can produce knowledge to solve/mitigate design compliance issues and may influence future applications in the building industry.

4.4 Design Science Methodology

This study has developed a BIM-CCS that is seen as a purpose-built artefact that solves the identified research problems. Artefacts can be investigated through different scientific domains, such as formal sciences, behavioural sciences and social sciences. For example, computer science (formal science) research can examine the properties of algorithms to produce visualization models. Psychology (behavioural science) can explore how online games influence the release of stress. Administration (social science) can investigate how the adoption of product lifecycle management (PLM) systems affects innovation management (Johannesson and Perjons 2014).

Apart from the abovementioned domains, artefacts can also be studied in Design Science. Design Science is ‘… the scientific study and creation of artefacts as they are developed and used by people with the goal of solving practical problems of general interest’ (Johannesson and Perjons 2014: 7). The artefacts are developed as solutions to problems that people may encounter in practice. Artefacts are viewed as a means of supporting people dealing with practical problems. This highlights the significance of Design Science methodology differentiating from the other research domains (i.e. formal science and behaviour science). Design Science researchers always take on the positive roles of designers creating objects as well as the development process of artefacts. These are hugely affected by the target audience. Once the problems have been solved or at least mitigated, the artefacts and the knowledge to produce them are the research outcomes of design science research (Johannesson and Perjons 2014).

This study argues that using a BIM-CCS in the design process can help solve design compliance issues in the context of Australian construction industry. This is underpinned by studies that demonstrate that practical problems can, in many cases, be solved by means of artefacts (Hevner, A. and Chatterjee 2010, Purao 2002). There are many artefacts in the area of the Information Technology and/or Information System that involves relationships between people, practices, and problems (Gregor and Hevner, A. R. 2013, Hevner, A. and Chatterjee 2010, Johannesson and Perjons 2014). Figure 4.1 illustrates people engaging in practices where the problem may be perceived and can be addressed by means of artefacts.

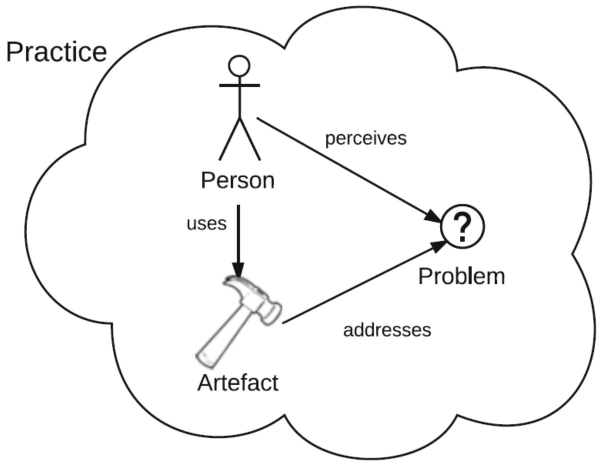


Figure 4.1 People, practices, problems, and artefacts

Source: (Johannesson and Perjons 2014: 4)

Design Science research involves five sequential procedures: awareness of problems, suggestions, development, evaluations and conclusions (Figure 4.2) (Hevner, A. and Chatterjee 2010). A typical design science research steps as follows:

Awareness of problem: An awareness of an interesting problem that may have resulted from diverse sources. Awareness can be raised by practical experiences or through observations of daily life. The output of this stage is a proposal, whether formal or informal, to assist efforts on innovative research.

Suggestion: This comes after the awareness of problems and begins with tentative designs. This is essentially a creative stage. The output of this stage can be presented as a prototype based on existing, non-existing or mixed elements.

Development: This stage deals with the tentative design, with further development and implementation, finally reaching a realization stage. The techniques to create an artefact vary based on the artefacts to be presented. This highlights that novelty is the essence of design rather than the construction process of the artefact.

Evaluation: When the artefacts have been created, they need to be assessed for efficacy according to the criteria. Both qualitative and quantitative methods may be used for evaluation. These methods include case studies, simulations or experiments. It the evaluation results are not positive, it is necessary to revert to the suggestion stage. This iterative process needs to recur until satisfactory evaluation results are obtained.

Conclusion: Once the artefact has been verified, knowledge is produced from the whole development process.

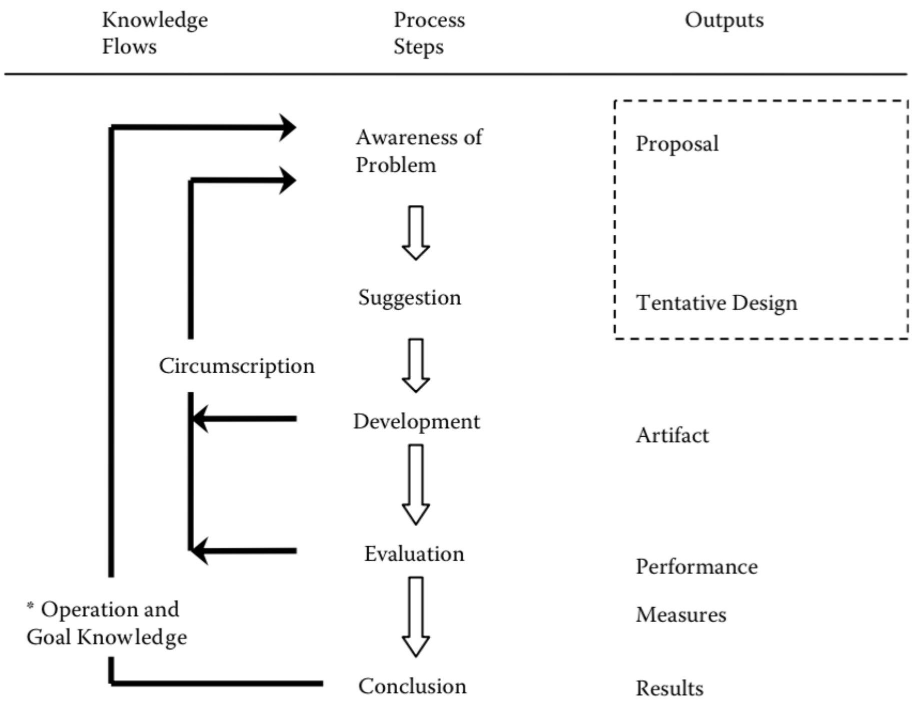


Figure 4.2 the general methodology of design science research

Source: (Hevner, A. and Chatterjee 2010: 20)

March and Smith (1995) emphasize an interactive process of two activities in Design Science research: build and evaluate. However, build and evaluate do not work sequentially but in parallel. Discovery and justification activities are repeated during the build-evaluation process. In order to secure the efficacy of the purpose-built artefact, scientific evaluation work is crucial and significant (March and Smith, G. F. 1995). In addition to featuring the build-evaluate process, Hevner and Chatterjee (2010) list eight characteristics of Design Science research which confirm its research focus, saying the research:

- Originates with a question or problem;
- Requires the clear articulation of a goal;
- Follows a specific plan or procedure;

- Usually divides the principal problem into more manageable sub problems;
- Is guided by the specific research problems, questions or hypotheses;
- Accepts certain critical assumptions;
- Requires collection and interpretation of data or creation of artefacts; and
- Is by its nature cyclical, iterative or more exactly helical. (2010: 3)

The iterative process of build-evaluate needs to be processed repeatedly and systematically during the artefact development process. This ensures that the developed artefact works effectively and ultimately meets its purpose. This cycle has assisted the researcher in seeking valid solutions to the identified problem and has assisted in creating new knowledge for the BIM-CCS research domain.

4.4.1 Design science guidelines

Within Design Science research, a set of principles has been proposed to facilitate the development of purpose-built artefacts (Hevner, von A. R. et al. 2004). These principles work as guidelines and can assist researchers to explore and understand the requirement of Design Science (Hevner, A. and Chatterjee 2010). These principles are shown in Table 4.2 and further discussed below:

Table 4.2 Design Science Research Guidelines

Guideline	Description
Guideline 1: **Design as an Artefact**	Design-science research must produce a viable artefact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: **Problem Relevance**	The objective of design-science is to develop technology-based solutions to important and relevant business problems.
Guideline 3: **Design Evaluation**	The utility, quality, and efficacy of a design artefact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: **Research Contributions**	Effective design-science research must provide clear and verifiable contributions in the areas of the design artefact, design foundations, and/or design methodologies.
Guideline 5: **Research Rigor**	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artefact.
Guideline 6: **Design as a Search Process**	The search for an effective artefact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: **Communication of Research**	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Source: (Hevner, von A. R. et al. 2004: 83)

Design as an artefact: The outcome of Design Science research can be an artefact of various forms. This includes constructs, models, methods, implementations and improved theories (March and Smith, G. F. 1995, Purao 2002, Rossi and Sein 2003).

Problem relevance: In this study, Design Science research has been used to produce artefacts to solve the problem of achieving design compliance. The designed artefacts are intended to be used to enhance the effectiveness of code checking activities within the design process.

Design evaluation: Evaluation activities are crucial in Design Science research and need to be rigorously conducted. Evaluation criteria have been developed and reviewed in many Design Science related studies. The techniques and methods used in the evaluation process for this study varied and are discussed in Section 4.5.2 (at page 76).

Research contribution: The contributions to Design Science research include:

> a) The created artefact needs to either contribute solutions to the identified problems or add value to the ways to develop artefacts in terms of methodologies, design tools and/or prototypes.
>
> b) Foundation: the ways to develop artefacts need to improve developed foundations.
>
> c) Methodologies: the ways to develop artefact need to improve the developed methodology.

Research rigour: The ways to create and evaluate the artefact need to be rigorous. The rigour can be found through selections of existing evaluation techniques and/or the applications developed by various research methodologies in the development and evaluation processes.

Design as a search process: The nature of Design Science is an iterative process of build and evaluate until solutions reach optimal conditions. It is similar to problem-solving methods that review and examine the available means of gaining the best solutions.

Communication of research: Design Science research must be presented and operated efficiently for technical and/or management-level users.

This study has used the above of Design Science research principles and framework as the basis for developing solutions to the identified problems. The ways to develop the artefact and the outcomes it produced are evaluated against these principles in Section 6.7 (at page 152).

4.4.2 Outcomes of the design science process

Feedback on *Ignis*, regarding the system design and the outcomes (results of reports), was obtained from interviews. The recorded data was transcribed and the resulting text analysed using qualitative analysis software. March and Smith (1995) proposed four general outputs for design science research: constructs, models, methods and instantiations. In addition, Rossi and Sein (2003) and Purao (2002) address a fifth output: improved theories. These five outputs are explained below:

- Constructs: the conceptual vocabulary of a domain.
- Models: a set of propositions or statements expressing relationships between constructs.
- Methods: a set of steps used to perform a task – how-to knowledge.
- Instantiations: the operationalization of constructs, models and methods.
- Improved theories: artefact construction as analogous to experimental natural science, coupled with reflection and abstraction.

These five outputs have been adopted as an evaluation framework for the BIM-CCS developed in this research. The data from interviews were transcribed, coded in qualitative analysis software, and analysed using an evaluation framework (described in section 4.6 at page 80). The outcomes generated from this evaluation framework were used to refine the artefact and establish knowledge for further studies.

4.5 Research approach

Qualitative research emphasizes exploring issues, understanding phenomena and answering questions by examining peoples' lives, experiences and behaviours, and the stories and meanings individuals ascribe to them (Creswell 2013, Creswell and Miller 1997). The context of this study highlights the design compliance activities (as research gaps) in design processes that stakeholders need to interact with, as well as building technologies and building regulations, project stakeholders and certifying authorities. These interactions are intertwined and make a complex environment. This study has created a BIM-CCS to mitigate these complexities. In this study, complexity has been explored through the use of qualitative research methods and techniques.

Qualitative approaches relate to data regarding human behaviour and thinking. This represents an eclectic and reasonable combination of sampling, and data collection, analysis, and representation techniques. Bernard et al. (2009) provides a graphical taxonomy of these methods in three main qualitative categories: indirect observations, direct observations and elicitation (Figure 4.3).

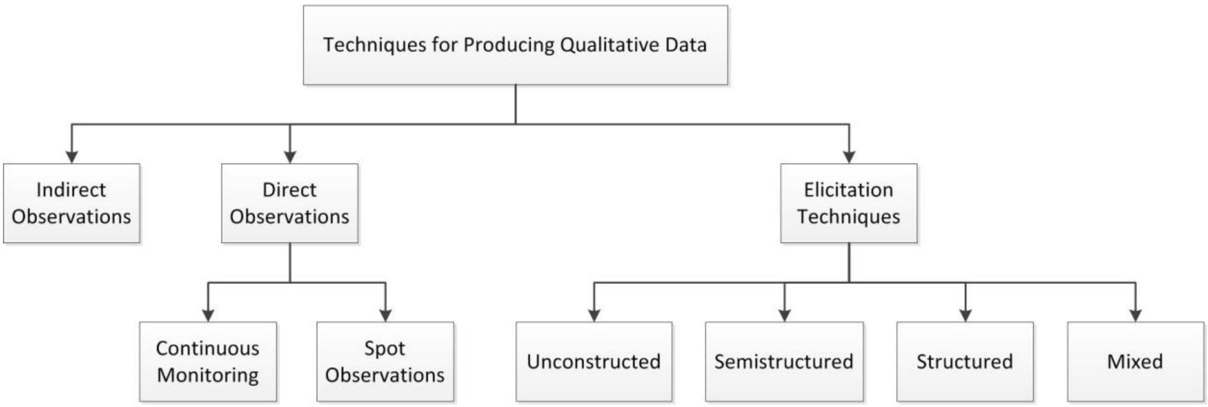


Figure 4.3 Taxonomy of qualitative data collection techniques

(Source from: Ryan and Bernard 2009)

Interviews have been used as a means of elicitation. This approach is widely used to collect qualitative data. Many studies have identified several strategic concerns through interviews of stakeholders involved in software implementations (Wilson et al. 1997, Boivie et al. 2003, Iivari 2005). However, Norgaard and Hornbæk (2006) argue that the methods adopted by these studies do not discuss in detail how activities (e.g. model checking in this study) are undertaken. This method assists in not only describing experiences from the perspective of real-life usability, but also presents detailed information about the subjects' thought processes. This has assisted in understand how the BIM-CCS could be used to facilitate stakeholders in developing their designs.

According to Barnard et al's (2009) study, the forms of elicitation include unstructured, semi-structured and structured interviews, as well as combinations of these approaches. Interviews are widely adopted to seek a deep understanding of the interaction between stakeholders. Thus, they were considered appropriate for a study that seeks to understand the impact of BIM-CCS on design development within the design process.

The methodology and methods used to collect data for analysis in this study have been reviewed and approved. Confirmation of ethics approval by the University of Newcastle (approval number H-2014-0093) is included in Appendix 1.

4.5.1 Techniques for *Ignis* development

The development of *Ignis* has drawn BIM and fire resistance codes together to inform the design of code-checking rules. Assessing building designs for compliance with fire resistance codes requires codes to be interpreted regardless of whether these are assessed manually or via computerized assessments. Interpreting the codes for manual assessments is an implicit internalization process, whilst *Ignis* needs the codes to be interpreted in an explicit manner. Semantic analysis methods can be used to facilitate this. These methods can identify code requirements and the relationships between them. BIM parameters then can be explored against the identified requirements. Two semantic analysis methods, RASE and the Dialog Language, were used to interpret fire resistance codes for rule designs. These are introduced below.

4.5.1.1 RASE

This semantic approach enables AEC professionals to develop rules that can be applied to the semantic content of IFC-based BIM models. The general rules contained in regulations consist of more than one "check" and typically represent a section of a regulation. A check can be analysed into four constructs: Requirement, Applicability, Selection and Exception (RASE). Requirement is related to the imperatives "Shall" or "Shall Not", and a check needs to contain at least one requirement. Some specific texts are identified as the Applicability of the check. For instance, "internal walls" compound the "internal" and "walls" concepts. The construct Selection is similar but distinct from Applicability, which is used for alternative subjects (e.g. doors, windows and other openings). The last construct, Exception, is the opposite of the Applicability. These can be summarized as a regulation that includes more than one "check" and each check contains a number of the four constructs described above. The formulations and an example clause are shown below (Table 4.3**)** (Hjelseth, E. and Nisbet, N. 2010).

Table 4.3 RASE formulations and examples

Formulations:	Check: C0 = R0 or NOT A0 or NOT S0 or E0 Regulation: Regulation0 = C0 and C1 and C2…Cn
Example Clause: (ICC IECC 2006 502.5 Moisture control)	All framed walls, floors and ceiling not ventilated to allow moisture to escape shall be A S S E provided with an approved vapour retarder having a permeance rating of 1 perm or … R R

Legend: R – Requirement; A – Applicability; S – Selection; E – Exception; C – Check

Adapted from: (Hjelseth, E. and Nisbet, N. 2010)

4.5.1.2 **Dialogue Language (DL)**

According to Omari and Roy's (1993) study, a DL has been developed to interpret Life Safety Codes (LSC) for Australia in an expert system. It adopts a consistent interpretation to represent the code clauses as well as the interactions between users and the expert systems. The DL provides systematic structures that organize the hierarchical dialogue of codes. These structures contain eight primary items (Table 4.4). Among them, the comment is used to explain the semantic meaning of the clause text. It is related to the object defined by the code violation and assists in explaining the noncompliance of the building design to the codes (Omari and Roy 1993).

Table 4.4 The components of Dialogue Language (DL) structure

Dialog_id	An identifier which references a dialog.
Parent_id	An identifier which points to the dialog from which the current dialog was referenced.
Code_violation	The id of the object to which evaluation error messages are to be attached.
Clause	The actual text of the clause from the BCA which is embodied within the current dialog.
Condition	The DL interpretation of the conditions which must be satisfied for this dialog to be applicable.
Action	The DL interpretation of the actions to be carried out if the conditions for application of the dialog are met.
Comment	An explanatory note which describes the reasons for the application of this dialog. This field is primarily to indicate to the user, why a particular dialog has failed, in simpler terms than can normally be available from the raw code clauses. This text field is attached to the frame identified by the Code violation field to indicate non-conformance of building model elements of the BCA.
Dependency	A list of property value identifiers which is used during the evaluation of a dialog. This field can be used to indicate the values of the properties used by the dialog. As such they provide a reference by which the user can determine the exact property which is not valid.

Adapted from: (Omari and Roy 1993)

4.5.2 Techniques for *Ignis* evaluations

This section introduces the methods used for evaluating the *Ignis*. Within Design Science methodology, evaluation methods vary and include observations, simulations, laboratory experiments and mathematical proofs. Peffers et al. (2007) group all evaluations into two activities: demonstration and evaluation. Demonstration activities present as ‘pre-evaluations’ to demonstrate that the artefact works feasibly to ‘solve one or more instances of the problem’ (Pries-Heje et al. 2008: 88).

Evaluation activities are more formal and extensive. They lend themselves to the positivistic view that evaluation activities need to evaluate how well the purpose-built artefact performs as a solution to the identified problems. Peffers et al. (2007) observes that evaluation methods may include objective performance measures, the results of satisfaction surveys, clients (users) feedback or computer simulations and mathematical proofs.

The techniques used in evaluating *Ignis* for this study are discussed in the following sections. They include demonstrations, interviews and focus groups.

4.5.2.1 Demonstrations

Demonstration methods (or ‘doing’ method) are usually used for teaching and/or delivering knowledge and skills (Lankford 1943). Demonstrations feature ‘step-by-step’ tasks. This approach highlights explaining the reasons for and the significance of each step. A significant benefit of using demonstrations is to make complex task easy to understand (Glasson 1989).

The demonstrations used in this study involved explaining the code-checking rules as well the procedures of operating the BIM-CCS. The explanations of the code-checking rules focused on decision-making processes. These processes are conducted step-by-step and enable accredited certifiers to understand how the rules operate and how each rule is assessed. This is because the process of interpreting code clauses into rules is a mental process that cannot be physically or mathematically assessed.

Demonstrating how the BIM-CCS is used can help users understand how it operates and interacts with users. These procedures highlighted importing BIM models, commencing code-checking activities and producing reports. Users were able to appreciate the overall concept of the BIM-CCS and thereafter to provide feedback to assist the researcher to revise the BIM-CCS.

4.5.2.2 Interviews

Research Interviews are normally categorized in three groups: structured, semi-structured and unstructured (Patton 2001). Structured interviews require adherence to a particular set of rules and are used mostly by quantitative researchers (Louise Barriball and While 1994, Myers and Newman 2007), while unstructured interviews have the most relaxed rules of the three without any order and script (DiCicco-Bloom and Crabtree 2006) but may result in aimlessness (Nicholls 2008). Semi-structured interviews are adopted more often in qualitative research. Many researchers like to use semi-structured interviews because questions can be prepared ahead of time. This allows the interviewer to be prepared and appear competent during the interview (Wengraf 2001).

Data obtained using this approach are larger than those with structured interviews (Malterud 2001). The benefits of semi-structured interviews include the ability to gain rapport and participants' trust, a deeper understanding of responses, as well as obtaining reliable, comparable qualitative data (Nicholls 2008). Moreover, additional relevant questions may be asked by the interviewers during the interviews. The interview questions that were used to guide the interviewees with accredited certifiers and architects are shown in Table 4.5 and 4.6.

Table 4.5 Semi-structured interview questions for accredited certifiers

System structures

1. How do you think if it is useful using a BIM-enabled code-checking system (BIM-CCS) to link the "BCA" and "BIM technology / users"?
2. Do you foresee any issues with the information we extract / use /define from the BIM models? Will any be ineffective or problematic for checking processes?

Code-checking Rules

3. Do the procedures incorporated in our BIM-CCS follow those you would usually adopt when checking building designs for Section C Fire Resistance of BCA?
4. In your view, how effective are the checking processes used in the BIM-CCS compared to your normal certification processes?
5. Do you think any procedures used in the BIM-CCS have the potential to cause inconsistent results?

Report Information

6. When you complete a manual certification task, what information do you need to identify in reports?
7. How does the information provided in the visualization reports (generated by the BIM-CCS) assist you?
8. What information in the visualization reports is lacking / insufficient / unnecessary and how could this be improved?

System Interfaces

9. What do you think of the operability of the BIM-CCS?
10. What problems or difficulties do you foresee in obtaining the information you need when you use it? What do you suggest in this regard?
11. What are the benefits of the BIM- CCS for you when conducting a certification task?
12. Do you foresee any problems with the BIM- CCS when conducting a certification task?

Table 4.6 Semi-structured interview questions for architects

System structures
1. How do you think using a "BIM-enabled code-checking system (BIM-CCS)" to link the BCA (compliance activities) and BIM (users)?
2. How do you think engaging BCA assessment activities using BIM-CCS into design processes? Can you also compare this to your own BCA compliance activities during your design processes?
3. Can you foresee any obvious problems with how we implement this system in the design processes? (For example, any issues with the information we extract / use from the BIM models? Will any be ineffective or problematic for checking processes?)
Report Information
4. How does the information provided in the visualization reports (generated by the BIM-CCS) assist you?
5. What information in the visualization reports is lacking / insufficient / unnecessary and how could this be improved?
System Interfaces
6. What do you think of the operability of the BIM-CCS? (For example, how engaging is the interface? Can you get good feedback/interaction?)
7. What are the benefits of the BIM- CCS for you when conducting a building design?
8. Can you foresee any problems with the BIM- CCS when conducting a design project? What do you suggest in this regard?
9. What features of this system do you like or have suggestions about?
10. Would you suggest any functions of the BIM-CCS that you think can be beneficial to assist your designs during the design process?

4.5.2.3 Focus groups

Focus groups are a form of group interview. However there are essential differences. Group interviews emphasize questions and responses between the researcher and participants while focus groups rely on interactions within the group based on topics given by the researcher (Morgan and Krueger 1997). Powell and Single (1996) propose a definition of focus groups:

> “A group of individuals selected and assembled by researchers to discuss and comment on, from personal experience, the topic that is the subject of the research”. (Powell and Single 1996: 499).

The number of participants is also an important concern. If only a few participants are present, conversation may be less dynamic and more like an interview. Conversely, too many participants may not provide participants with opportunities to fully engage with one another around the topic. Although there are no precise prescriptions, focus groups generally include six to eleven participants (Morgan and Krueger 1997). Significantly, focus groups require dynamic interactions, both verbal and nonverbal. Communication technologies allow several people to interact with one another from a distance (including virtual focus groups, or focus groups that are conducted by conference calls or videoconference). Additionally, technological instruments such as one-way mirrors and high-quality recording equipment may assist in collecting data as well. In this study, focus groups were held to understand the effects on project stakeholders of implementing code-checking systems in the design process.

4.6 Evaluation framework

Design Science methodology research emphasizes the significance of the evaluation process (Hevner, A. and Chatterjee 2010). Evaluation can assist in purpose-built artefacts (as the outcomes of research) reaching satisfactory quality and performance, and can contribute to understanding whether the artefacts are able to solve problems as intended. Several benefits of the evaluation process are identified by (Petter et al. 2010) as:

- Evaluating the artefact needs to confirm whether the artefact offers improved solutions to current practices (Nunamaker Jr and Chen, M. 1990, Vaishnavi and Kuechler 2015).
- Feedback from the evaluations can assist the researcher to clarify problems, verify assumptions, examine development processes and identify refinements for the artefacts (Hevner, von A. R. et al. 2004).
- The evaluated artefacts can use social research approaches to inform theories or explanations about why the artefacts worked or did not work in particular environments (March and Smith, G. F. 1995).

The artefacts produced by Design Science methodologies are varied. Each type of artefact has specific characteristics and thereby the evaluation criteria must be different. Petter at al. (2010) emphasize that the purpose of an artefact needs to be known when dealing with evaluation activities. This can be achieved by asking questions such as ‘Does the artefact or theory work?' and 'How useful is the artefact or theory'. In addition to the type of artefact, the research context and environment where the artefact is used need to be considered when setting the evaluation criteria (March and Smith, G. F. 1995, Petter et al. 2010). Various evaluation criteria have been proposed in many Design Science studies (Goodhue 1995, Hevner, von A. R. et al. 2004, March and Smith, G. F. 1995, Markus et al. 2002, Petter et al. 2010, Venable, J. R. 2010). These evaluation elements have been collected and used in Kanjanabootra's research (2013) and include: Functionality, Better solution, Quality, Efficacy, Performance, Reliability, Consistency, Effectiveness, Accuracy, Predictive, Feasible, Ease of use, Impacts on environment and users, Presentable, Usability, Understandability, Simplicity, Level of completeness, Quantitatively measureable, Testable against all requirements, Plausible, Side effects and The process is contributing to knowledge. However, these are not all compatible with the evaluation of the BIM-CCS. The evaluation elements chosen for this study relate to the four topics set in the interview questions. The selected evaluation elements for each topic are discussed separately below.

4.6.1 System structure

The BIM-CCS is structured with the inner and outer environments (March and Smith, G. F. 1995, Petter et al. 2010). The inner environment is the set of components (informer, ruler, communicator and reporter) identified in section 3.6.10 (at page 54). How these components behave and interact determine the functionality of the BIM-CCS. Moreover, since the BIM-CCS is a computer-based program, the efficiency in dealing with code-checking activities needs to be explored compared to manual certifying activities.

In terms of the outer environment, this focuses on the ways the BIM-CCS engages stakeholders and accredited certifiers in code-checking activities. The purpose of the BIM-CCS is to allow stakeholders to check building designs for compliance during the design process. The efficacy of how the BIM-CCS achieves this purpose needed to be explored. How do project teams and accredited certifiers assess whether the BIM-CCS provides a better solution to code compliance issues? How does the BIM-CCS affect users' behaviours (project stakeholders and accredited certifiers) when dealing with code-checking activities in the design process? These questions inform the evaluation elements of the system structure; Functionality, Efficiency, Better solutions, Impacts on environment and users, Efficacy.

4.6.2 Code-checking rules

Within the development stage, fire resistance codes need to be analysed to ensure code-checking rules are applied correctly. Two semantic analysis methods (RASE and

DL) were used to identify the requirements for each code (Hjelseth, Eilif and Nisbet, Nick 2011, Omari and Roy 1993). However, several code clauses contained requirements that BIM model parameters could not accommodate. This necessitated additional work including further calculations and/or manual input. These alternative ways of calculating and/or producing required parameters may affect the effectiveness of each code. It was therefore necessary for accredited certifiers to assess these rules and verify that they had been applied correctly.

As the requirements and relationships between code clauses had been identified through semantic analysis, the researcher then can create process models for each code. Each process model must produce a final choice and/or results. This highlights the consistency inherent in the way code-checking rules are executed. However, some BCA codes are ambiguous and open to interpretation. This compromises the manner in which of code-checking rules are designed. The gaps between open interpretation and code-checking rule designs were therefore identified as a challenge.

The conditions discussed above may affect the design of code-checking rules. Therefore Effectiveness and Consistency were identified as evaluation elements for evaluating code-checking rules.

4.6.3 Report information

In this study, the BIM-CCS can produce visualized and text-based reports. Both are presented in the assessment results for each code. Most accredited certifiers currently use this format when they produce their reports. However, there is no regulated report style for assessment results and formats can vary. These variations mean that stakeholders may be unfamiliar with certain formats and hence not completely understand some reports.

Moreover, the results presented on the reports must be correct. This includes whether the reports correctly identify whether drawing elements ‘comply’ or ‘do not comply’ and the reasons for their status. The reasons may need to identify specific model information such as which room (room number and name) and which level (level number and name) contains non-compliant walls (wall numbers). It should be noted that many manual reports do not provide this detailed information.

It is also interesting to explore what stakeholders can obtain from reports and/or what they can do with the reports. These considerations informed selection of the evaluation elements for assessing report information as Understandability, Reliability and Side Effects.

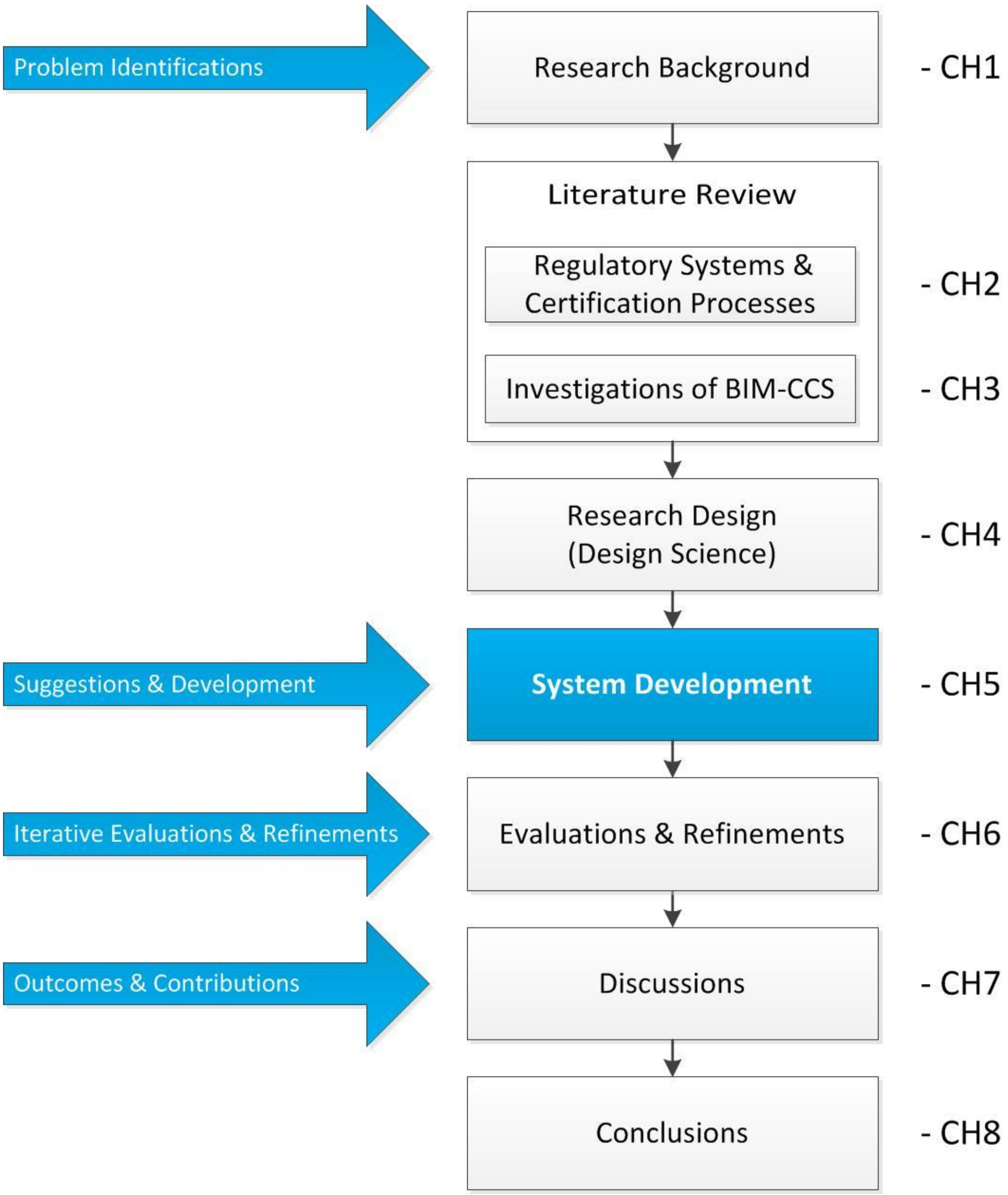
4.6.4 System interfaces

The BIM-CCS requires an interface that users can interact with for code-checking activities. In general, users interfaces are hierarchically constructed. Within this hierarchical structure, either straight-forward or explanatory indications are needed for each level. This assists users to progress through the system and to obtain feedback and/or results. The BIM-CCS interfaces were designed to be simple and straight-forward so that users could produce assessment results and reports with a few clicks. Furthermore, the visualized reports enable users to find the locations of problematic model objects. Users are then able to revise model designs immediately. Therefore, Simplicity and Usability are the two evaluation elements used for this topic.

4.7 Summary

The research has adopted Design Science to create and evaluate a purpose-based BIM-CCS as an artefact to solve design compliance issues during the design process. The Design Science methodology emphasizes the iterative process of building and evaluating artefacts. In order to build the BIM-CCS for this study, two semantic analysis methods (RASE and DL) have been proposed to interpret fire resistance codes in a systematic manner. The evaluation framework based on Design Science related studies, have been adopted as an evaluation tools to evaluate system structure, code-checking rules, report information and system interfaces. The evaluation methods are based on qualitative methods including demonstrations, interviews and focus groups. The ways in which the BIM-CCS for this study have been built and evaluated are discussed in the following chapters.

5 SYSTEM DEVELOPMENT OF *IGNIS*



5.1 Introduction

This chapter describes how *Ignis* has been designed and evaluated using testing models to achieve the research objectives. *Ignis* implements code-checking activities for Section C Fire Resistance codes of BCA for commercial buildings (as described in section 1.4 at page5 and section 1.5 at page 7). *Ignis* thus provides a proof of concept prototype and an outcome within Design Science research.

The entire *Ignis* system structure is discussed first in the next section. Investigations of available BIM-CCSs (at section 3.6, page 44) provide an underpinning to the *Ignis* structure. These shape the *Ignis* structure outlining how components communicate and interact with each other. The *Ignis* prototype has been built as a plug-in embedded in BIM software packages. Section 5.3 highlights the ways the code-checking rules have been designed. This includes interpreting code clauses to inform rule designs and identifying the required BIM parameters. Several challenges and their proposed solutions are then discussed. A range of testing models was built to examine the effectiveness of rule designs. The *Ignis* interfaces that enable users to commence code-checking activities and interact with the *Ignis* system are illustrated and discussed in section 5.4. After commencing a code-checking activity, *Ignis* can produce both visualized and textual reports of assessment results. The ways *Ignis* presents this information in reports and the ways users use and/or interact with reports are then discussed in section 5.5.

5.2 System structures

As the survey of developed BIM-CCSs discussed in section 3.6 (at page 44), several BIM-CCSs are built using an independent platform engaging rule engines and IFC-based models (Nepal et al. 2013, 2008). Rule engines (investigated in section 3.5 at page 42) highlight the abilities to deal with checking dimensional issues such as 'width of corridors'. However, several conceptual and/or descriptive requirements of building clauses may not be addressed through these engines (such as Solibri). In addition, rule engines are expensive commercial BIM extensions and were deemed inappropriate for a research-based PhD study.

In terms of the BIM information, this study chooses Revit models to provide the required parameters for code-checking activities. Although IFC-based formats are promoted as vehicles for communicating between different BIM software (buildingSMART 2009b), in certain cases, IFC-based models are not able to share all information between BIM vendors' extensions because the rules (in each BIM package) are not well communicable and poorly aligned (Pazlar T 2008). Moreover Le et al. (2006) examined and verified that importing/exporting IFC models between Revit and ArchiCAD can result in broken geometric objects and the loss of properties of model elements. These undoubtedly bring risks for code-checking activities and impede the potential of independent BIM-based extensions. Regardless of whether the BIM-CCSs operate independently or via third-party platforms (i.e. Solibri), they generally include four activities (Shih and Sher 2012):

- filtering required information from BIM models,
- interpreting building regulations into program rules,
- examining the filtered information (the first activity) against the rules (the second activity), and

- producing a report showing the results of examinations (the third activity).

Ignis was created as a plugin embedded in *Autodesk® Revit®* 2014. Revit was selected for several reasons. Statistics (shown in Figure 3.4 at page 36) have identified Revit as having the largest BIM market share at 49% (Hamil 2013). Furthermore, *Autodesk® Revit®* contains an open-source code feature, Revit Lookup, which allows plugins to be developed and embedded in Revit.

Plugins can augment Revit's abilities to assist stakeholders to improve efficiency, enhance quality and solve problems for design projects during the design process. Moreover, users are able to modify models directly in the Revit environment when *Ignis* instances of non-compliance are identified. This is not possible when external platforms like Solibri are used. Importantly, plugins can help Revit enhance IFC project data to communicate with other BIM software (i.e. ArchiCAD) and obtain improved interoperability (GRAPHISOFT 2007). This makes it possible for BIM models from other vendors to engage in code-checking activities through the Revit platform.

The system structure of *Ignis* is depicted in Figure 5.1. It firstly interprets the fire resistance codes to identify the required BIM model information through semantic analysis methods. The BIM model information is then explored through Revit Lookup according to the identified requirements of BCA clauses. The rules are subsequently created as a plugin embedded in Revit. The ways interpretation results are used to inform rule designs are further discussed in next section.

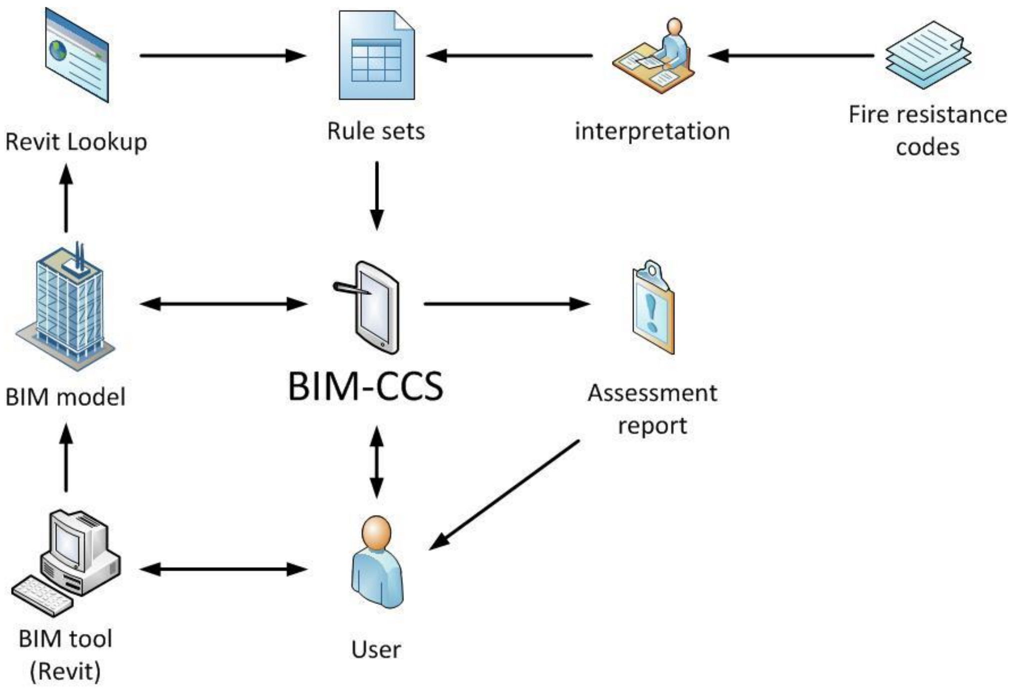


Figure 5.1 The system structure of *Ignis*

5.3 Code-checking rules

BCA codes are seen as complex and possibly contradictory (Yatt 1998). Many code clauses contain cross references and open-ended conditions that may hinder the development of rule designs (Fischer, J. and Guy 2009, Montoya 2013). Code clauses need to be interpreted to inform rule designs. Semantic analysis methods are usually used to facilitate interpretations. RASE and DL methods as discussed in section 4.5.1 (page 74) were used to interpret code clauses for rule designs. RASE provides a systematic method to deconstruct code clauses into elements and categorize them into four groups: Requirement, Applicability, Selection and Exception. This assists in outlining the interrelationships between elements. DL sets all code clauses in a hierarchical structure that can identify their affiliations.

The Fire Resistance codes have been semantically analysed. An example of Table C2.2 'General floor area and volume limitations' is introduced below (Table 5.1). Though the DL method, the code hierarchical structure can be built. This example shows this rule is Table C2.2 in 'Dialog' and its 'Parent' code is 'C2.2'. Code details are shown in the 'Clause' describing the values of maximum floor area and volume for building classification against different Type of Construction. The RASE method is then used to identify the key requirements for the Table C2.2 as Class 5 to 9, the floor areas and volumes, and Type of Constructions.

Table 5.1 Semantic analysis for Table C2.2

Dialog	C2_2_Table C2.2				
Parent	C2_2				
Code Violation	Exceed the max floor area or volume.				
Clause	Classification		Type of construction of building		
			Type A	Type B	Type C
	5, 9b or 9c aged care building	max floor area -	8 000 m2	5 500 m2	3 000 m2
		max volume -	48 000 m3	33 000 m3	18 000 m3
	6, 7, 8 or 9a (except for patient care areas)	max floor area -	5 000 m2	3 500 m2	2 000 m2
		max volume -	30 000 m3	21 000 m3	12 000 m3
	Note: See C2.5 for maximum size of compartments in patient care areas in Class 9a health care buildings.				
Interpretation: The pairs of building classes and type of construction provide the limitations in floor area and volume above					

RASE analysis									
Phrase	Type	Object Type	IFC Support	Revit Object	Revit Property	Comparison	Target Object	Target Value	Unit
Class 5 to 9	Applicability	Building/Space	IfcFooting/IfcZone.LongName (new in IFC2x4)	Room	Room Tag/Name	Includes	Rule C Table 2.2	Room tag	-
Type A to C	Applicability	Building/Space	-	-	-	Includes	Rule C Table 2.2	Refer to Table C1.1	-
8 000 m2 (and others)	Selection	Space	IfcSlab->IfcQuantityArea.Name="GrossSurfaceArea"	Floor area	Floor/Area	Less then	Floor area	8 000	m2
48 000 m3 (and others)	Selection	Volume	-	-	-	Less then	Volume	48 000	m3

After the semantic analysis, the rule designs were illustrated as process models shown in Appendix 2. The example Table C2.2 has been presented as a process model in Figure 5.2. This began with checking of the Class of Building for each storey, followed by an examination of the floor area and volume in accordance with the Class of Building against the identified Type of Construction. Calculating the required floor area and volume for a building of multiple uses was considered in this rule. The calculation method is explained in the yellow area of Figure 5.2. The process models enabled the researcher to communicate with a professional programmer. The programmer who is familiar with Revit plug-in designs was employed to translate the process models into software.

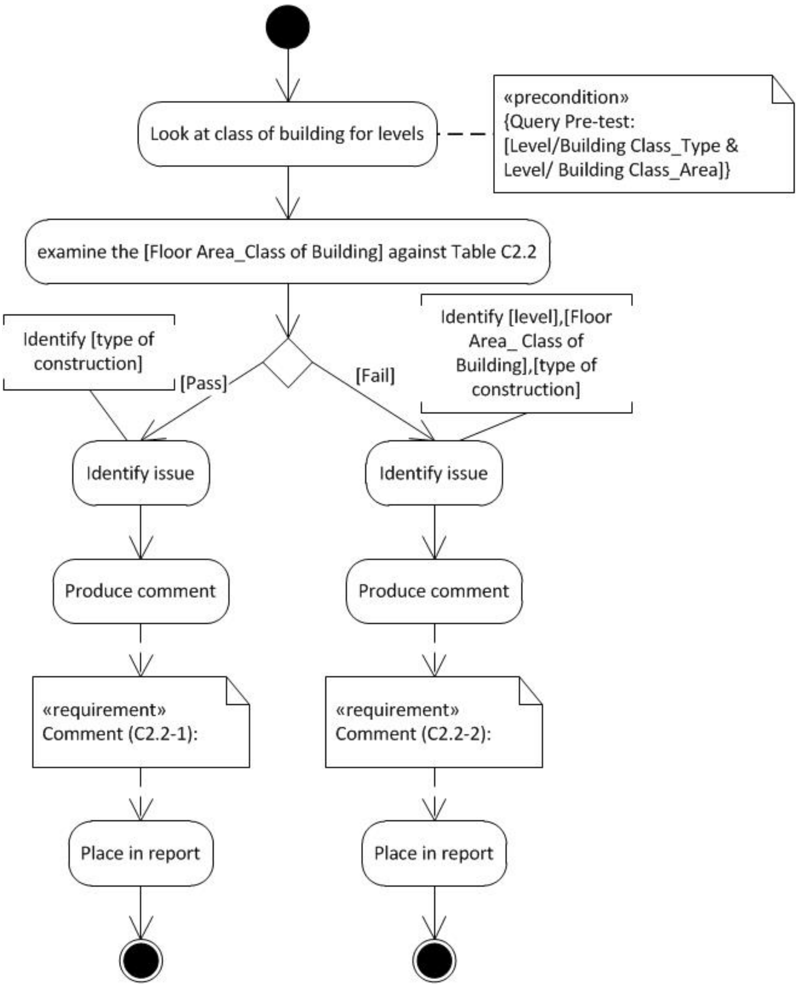


Table C2.2 MAXIMUM SIZE OF FIRE COMPARTMENTS OR ATRIA

Classification		Type of construction of building		
		Type A	Type B	Type C
5, 9b or 9c *aged care building*	max *floor area*—	8 000 m^2	5 500 m^2	3 000 m^2
	max volume—	48 000 m^3	33 000 m^3	18 000 m^3
6, 7, 8 or 9a (except for *patient care areas*)	max *floor area*—	5 000 m^2	3 500 m^2	2 000 m^2
	max volume—	30 000 m^3	21 000 m^3	12 000 m^3
Note: See **C2.5** for maximum size of compartments in *patient care areas* in Class 9a *health care buildings*.				

Example

Figure C2.2 shows a building of Type C construction containing a factory (Class 8) with an office (Class 5) at the front. The total area of the building is 2 100 m^2.

The area of the Class 8 portion of the building is 80% (1 680 m^2) of the floor area of the whole building (that is, the combined Class 8 and Class 5 portions).

The area of the Class 5 portion of the building is 20% (420 m^2) of the floor area of the whole building (that is, the combined Class 8 and Class 5 portions).

To determine if such a building complies with **Table C2.2**, the following calculations are necessary:

- Maximum area of Class 8 allowed by Table C2.2 = **2 000 m^2**
- The percentage of Class 8 is 80% = 80% of 2 000 m^2 = **1 600 m^2**
- Maximum area of Class 5 allowed by Table C2.2 = **3 000 m^2**
- The percentage of Class 5 is 20% = 20% of 3 000 m^2 = **600 m^2**
- Maximum allowable floor area = 1 600 + 600 = **2 200 m^2**

The maximum allowable floor area of the building is **2 200 m^2**. Therefore, the building in this example complies with the floor area component of **Table C2.2**. The fact that the Class 8 portion exceeds 1 600 m^2 is irrelevant for the purposes of this process. However, that portion is not permitted to exceed 2 000 m^2.

It should be noted that the maximum allowable volume must also be considered when determining whether the building complies with **Table C2.2**.

Figure 5.2 Process model for Table C2.2

5.3.1 Code elements analysis

Code-checking rules can be designed and presented in process models through code analysis using RASE and DL methods. The identified code elements have been further categorized in Appendix 3. This highlights several codes that may be challenged for given designs at the current stage. Relevant examples (extracted from Appendix 3) are shown in Table 5.2.

Table 5.2 Instances of code elements analysis

Object	Code	RASE	O	X	A	Comments
Theatres	C1.0(a)(iii)	A		V		Refer to Part H1
	C1.0(b)(iii)	A				Refer to Part H1
	C1.8(a)(ii)	A				Refer to Part H1
	C2.0(a)(iii)	A				Refer to Part H1
	C2.0(b)(iii)	A				Refer to Part H1
Stages	C1.0(a)(iii)	A		V		Refer to Part H1
	C1.0(b)(iii)	A				Refer to Part H1
	C2.0(a)(iii)	A				Refer to Part H1
	C2.0(b)(iii)	A				Refer to Part H1
Public halls	C1.0(a)(iii)	A		V		Refer to Part H1
	C1.0(b)(iii)	A				Refer to Part H1
	C2.0(a)(iii)	A				Refer to Part H1
	C2.0(b)(iii)	A				Refer to Part H1
Proscenium curtain	C1.10(a)(v)	A	V			Refer to specification H1.3
Escalators	C1.10(a)(vi)	A	V			Refer to specification D1.12
Moving walkways	C1.10(a)(vi)	A	V			Refer to specification D1.12
Plaster	C1.10(c)(i)	A	V			Refer to C1.10(a)
Cement render	C1.10(c)(i)	A	V			Refer to C1.10(a)
Concrete	C1.10(c)(i)	A	V			Refer to C1.10(a)

Legend: O=available BIM parameters; X=unavailable BIM parameters; A=additional calculations

The first issue illustrated in Table 5.2 is that the identified code elements cannot be informed by BIM parameters. These examples are specific buildings that influence many of the codes identified in this table. Moreover, these specific buildings have additional requirements that refer to other parts of the BCA. Catering for these instances is outside the scope of this research. In addition, several code elements contain multiple hierarchical cross references that may result in barriers for rule designs. For example, plaster, cement render and concrete are code elements in code C1.10(c) that need to refer to C1.10(a). However, Proscenium curtain, Escalators and Moving walkways within C1.10(a) have to refer to Specification H1.3 and D1.12. This hierarchical relationship complicates the ways rules are designed, particularly when the reference codes are out of the research scope.

These issues have determined whether code clauses are interpreted for rule designs at a particular stage. Several code clauses have been excluded in this study. The code clauses that have been addressed are identified in Table 5.3.

Table 5.3 Achievable code clauses

Code clause	Reference
Part C1	Fire Resistance and Stability
C1.1	Type of construction required
C1.2	Calculation of rise in storeys
C1.3	Building of multiple classification
Part C2	Compartmentation and Separation
C2.1	Application of Part
C2.2	General floor Area and Volumes Limitations
C2.5	Class 9a and 9c buildings
C2.7	Separation by fire walls
C2.8	Separation of classification in the same storey
C2.9	Separation of classifications in different storeys
C2.10	Separation of lift shafts
C2.11	Stairways and lifts in one shaft
Specification C1.1	
Table 3	Type A construction FRL of building elements
Table 3.9	Requirements for carparks
Table 4	Type B construction FRL of building elements
Table 4.2	Requirements for carparks
Table 5	Type C construction FRL of building elements
Table 5.2	Requirements for carparks

5.3.2 Intrinsic code elements

Although several code elements cannot be informed by BIM parameters, they are intrinsic to entire rule designs. These code elements are identified in the Table 5.4. The first one is the ‘Type of Construction’ that sets fire resistance levels (FRL) for building elements (e.g. walls and columns). The type C construction has the least FRL requirements, while type A construction sets the highest requirements. Unfortunately, this cannot be discerned from BIM parameters because the Type of Construction is determined by the other two intrinsic code elements, ‘Rise in Storeys’ and ‘Class of Building’. Rise in Storeys can be determined by floor plans while Class of Building can be challengeable depending on relevant determinations. Class of Building is determined in accordance with the use of a building. However, a building with multiple uses may complicate the determination process.

Table 5.4 Intrinsic code elements

Object	**Code**	**RASE**	**O**	**X**	**A**	**Comments/solutions**
Type of construction	C1.1(b)	R		V		
	C1.3(a)	A		V		
	C1.4	A		V		
	…	…				…
Storeys	C1.1(b)	A			V	Rise in storeys
	C1.2	A			V	Rise in storeys
	C1.5	A			V	Rise in storeys
	…	…				…
Class of building	C1.1(b)	A		V		
	C1.3(a)	S		V		
	C1.5(b)	A		V		Class 9c
	…	…				…
Fire-source features	Spec C1.1 Table 3	S			V	Type A
	Spec C1.1 Table 3.9	S			V	Type A Carpark
	Spec C1.1 Table 4	S			V	Type B
	…	…				…

Legend: O=available BIM parameters; X=unavailable BIM parameters; A=additional calculations

In addition to these, the distance between external walls and fire-source features (e.g. neighbouring buildings) is significant for determining FRL for external walls. However, fire-source features are usually not built for code-checking activities. These are critical code elements that need alternative solutions are discussed in the following sections.

5.3.2.1 Class of building

The BCA classifies buildings into two types: residential and commercial. Only commercial buildings (shown in Table 2.4 at page 20) are examined in this study. Some categories of commercial buildings may contain sub-categories (for example Class 7 buildings include Class 7a car parks and Class 7b warehouses). In current certification processes, developers need to lodge applications including design layout (i.e. site plans and floor plans) with local councils, thereby enabling accredited certifying authorities to determine the correct *class of building*.

5.3.2.1.1 Challenges

In any construction project, project stakeholders may not be able to identify the *class of building* correctly until consultants are involved in the design processes. This may result from project stakeholders being unfamiliar with the complexities of the *class of building* for a storey and/or a building. In some cases, consultants and even certifiers may determine the *class of building* in different ways. For example, various building practitioners may regard an assembly of people in a building for a particular activity as Class 6 or Class 9b. In BCA 2008 (Australian Building Codes Board 2013), the classification of a Class 6 use relates to any 'bar' area (which could include an assembly of people to meet, socialize and also possibly be entertained), whilst the Class 9b classification also refers to an assembly building where people may assemble to be entertained. Although the Class 6 building in BCA 2009 (Australian Building Codes Board 2013) refers a 'bar area that is not an assembly building', this inconsistency can result in different assessments. In such cases, the *fire-resistance level* of building elements, for instance, can be downgraded. This is a challenge for BIM-CCSs as ambiguities like these cannot be catered for.

5.3.2.1.2 Proposed solutions

Ideally, a building design needs area plans as well as parameters of the *class of building* for each area within a floor. This enables design proposals to be coordinated by project teams and certifiers from design through to certification. In reality, however, area plans are not always produced and the embedded parameters in some BIM extensions may not allow users to choose a *class of building*. Although users can manually add parameters for *class of building* in a parameter set, this requires additional effort on the part of stakeholders during the design process. As stakeholders making room tags in their designs are the norm in practice, the solution adopted in this study, preventing stakeholders from extra work, is to use room tags for determining the *class of building* (Figure 5.3). All information related to the room can be found in the Revit Lookup interface (Figure 5.4). For example, the storey it is located on and its floor area. This system has included a dataset element in a table form that contains the name of each room specific to each *class of building* (Figure 5.5). Several room names have been collected and categorized for each *class of building*. For example, *cafeteria* and *instruction* belong to class 6 and class 9b respectively. This table (Figure 5.5) also allows users to add or modify names for the *class of building*. This provides users with flexibility when a case (such as the bar area) needs modification.

It can be argued that this approach is inconsistent because the ways in which stakeholders nominate room names can be varied. However, project stakeholders generally nominate room names in a consistent manner. Therefore, once this table has been set up, there is no need to make modifications unless the clauses change. Another benefit is that no extra workload is required for stakeholders during the design process.

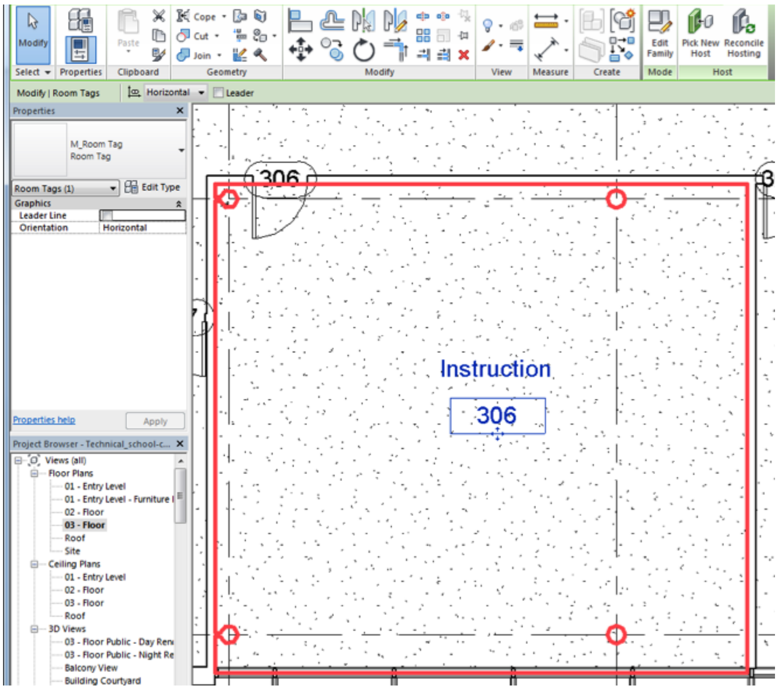


Figure 5.3 An example for room tag use.

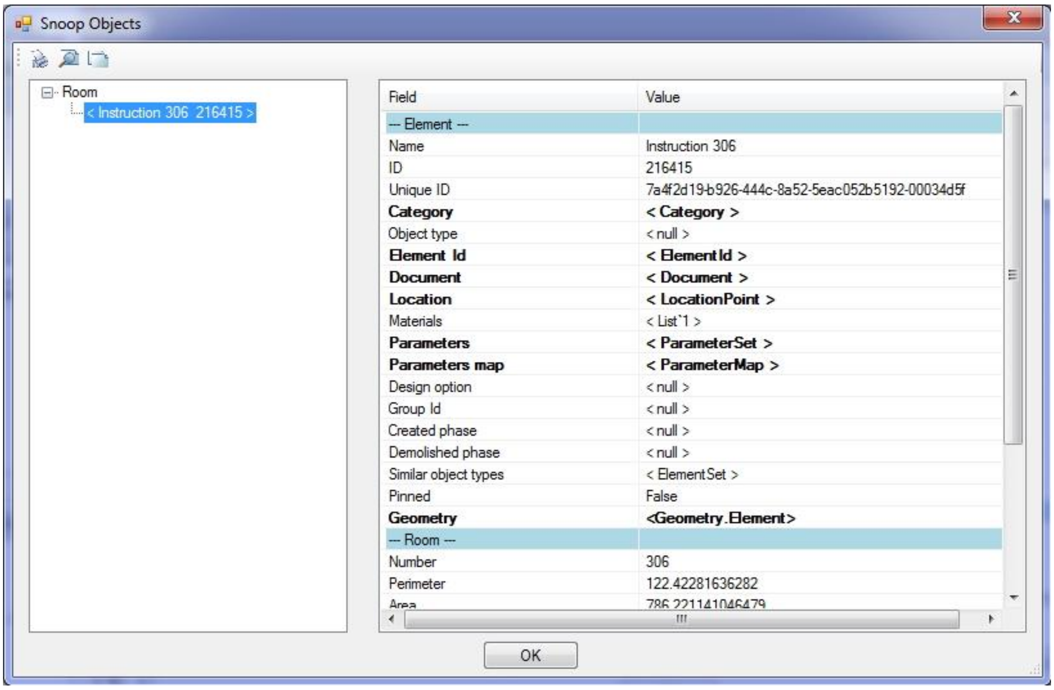
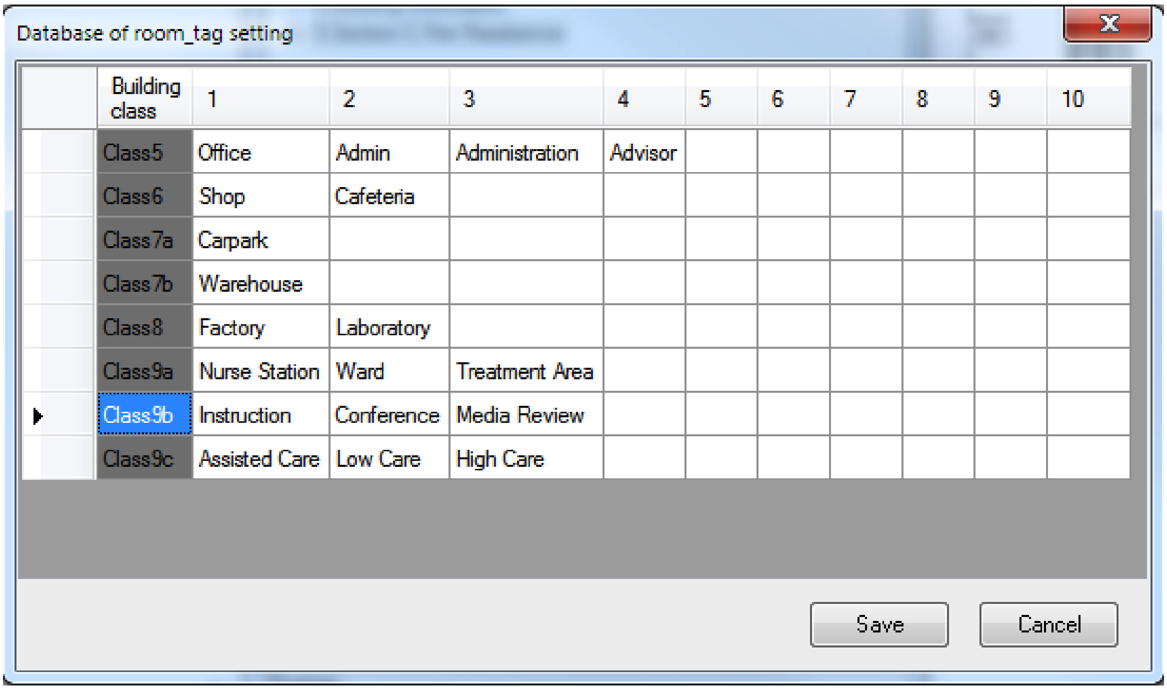


Figure 5.4 Room tag information shown in Revit Lookup.



Database of room_tag setting

Building class	1	2	3	4	5	6	7	8	9	10
Class5	Office	Admin	Administration	Advisor						
Class6	Shop	Cafeteria								
Class7a	Carpark									
Class7b	Warehouse									
Class8	Factory	Laboratory								
Class9a	Nurse Station	Ward	Treatment Area							
Class9b	Instruction	Conference	Media Review							
Class9c	Assisted Care	Low Care	High Care							

Save Cancel

Figure 5.5 Table for the class of building setup.

(All Autodesk screen shots reprinted with the permission of *Autodesk*®, Inc.)

5.3.2.2 Rise in storeys

The importance of *rise in storeys*, in general, is that the more storeys a building has, the higher the *fire-resistance level* that is required. A building having four or more storeys requires the highest level of fire-resistant *type of construction*. A general definition of the *rise in storeys* is that it is the sum of the greatest number of storeys above the ground level, and within the *external wall* and roof space. This highlights several key requirements when creating BIM models. For example, within the modeling process, site surfaces can define finished or natural ground. In addition, establishing storey planes for different levels shows the height of storeys, and setting a wall function as exterior for *external wall* helps determine the boundaries of a building.

According to BCA, the methods used to define the rise in storeys include several exceptions. The top level is not counted as a storey when it only contains service units (e.g. a heating or water tank). Furthermore, a storey classified in class 7 or class 8 may be counted as two storeys where such a storey has an average internal height of more than six meters within a two storey (or more) building. In addition, a *mezzanine* (or *mezzanines* at the same level) may be counted as an independent storey once its aggregate floor area exceeds 200 m^2, or if not, its aggregate floor area is more than one third of the floor area of the room. Some exceptions mentioned above unfortunately cannot be incorporated directly from BIM models and further calculations are necessary. In this regard, several challenges and suggestions are described below.

5.3.2.2.1 Challenges

Service units are one of several challenges that confront those designing BIM-CCSs. The BCA (Australian Building Codes Board 2013) stated that '…at the top of the building contains only heating, ventilating or lift equipment, water tanks, or similar service units or equipment' (2013: 102). The term 'similar' is an ambiguous term that IT systems cannot accommodate. The average internal height within a storey is another challenge. The information from BIM models can only establish the distance from one storey plane to another. This does not represent the accurate average internal height once floors, ceilings or roofs are divided in areas by diverse heights within a storey. A further calculation is needed to obtain the average internal height.

A further challenge, within BIM software, is that there are no embedded parameters to distinguish storeys or *mezzanines*. In most cases, project teams may set an individual storey plane for a *mezzanine* (or *mezzanines* at the same level), while some stakeholders may create *mezzanines* based on the storey plane of its next storey. All these challenges prevent BIM-CCS from obtaining correct model information for examination.

5.3.2.2.2 Proposed solutions

In order to find whether the top storey contains only similar service units, two issues need to be clarified. The first is to explore the mechanical equipment objects (in the service units) and the second is to check the function of the space on the top storey. Once this space is used for a purpose that is in addition to placing service units, this storey needs to be counted. This means that the room space and the mechanical equipment objects on the top storey need to have separate parameters to identify their use. This enables the use of the space on the top storey to be determined correctly. However, these two parameters unfortunately are not supported by BIM extensions. This study addresses this challenge by exploring whether the space on the top storey contains a room tag. Once a room tag is found, regardless of mechanical equipment, the top storey must be counted as one storey and vice versa.

Calculating the average internal height is problematic when the floors, ceilings and roofs have divided areas with varied heights and these divisions are not aligned and overlap. The solution this study has adopted is to divide the overlapped areas between floors and ceilings (or roofs) into segments to ensure each segmented area does not have more than two heights. The volume of each segment is then calculated. All segments' volumes are summed up and divided by the floor area to obtain the approximate average internal height.

As noted in the previous section, stakeholders can only create floors on storey planes whether the floors are used as storeys or *mezzanines*. BIM software treats a storey and a *mezzanine* (or *mezzanines* at the same level) in the same manner, and no parameters can tell them apart. As *mezzanines* are treated as storeys, additional constraints are needed to exclude the *mezzanines* that should not be counted as storeys. Calculations of the floor areas of each storey are used to determine whether storeys are to be considered as *mezzanines*. The BCA sets constraints for *mezzanines* as '…a *mezzanine* is regarded as a storey in that part of the building in which it is situated if its floor area is more than 200 m^2 or more than 1/3 of the floor area of the room…'(2013: 102). This means that *mezzanine* levels are seen as storeys. The floor area of every storey is then checked to see whether it exceeds 200 m^2, or more than one third of the floor area of its next storey.

5.3.2.3 Fire-source feature

Specification C1.1 of the BCA sets the required *fire-resistance level* of building elements (e.g. walls and columns) according to *type of construction* and *class of building*. An additional requirement for determining *fire-resistance level* of *external wall* requires measurement of the shortest distances from *external wall* to *fire-resource features*. A *fire-source feature*, according to the definitions of the BCA (Australian Building Codes Board 2013), is defined as '(a) the far boundary of a road, river, lake or the like adjoining the allotment; or (b) a side or rear boundary of the allotment; or (c) an *external wall* of another building on the allotment which is not a Class 10 building' (2013: 27). The challenges that arise from these conditions are described below, followed by suggested solutions to address them.

5.3.2.3.1 Challenges

According to the aforementioned clauses, a *fire-source feature* is a necessity in BIM models. They determine the minimum *fire-resistance level* for *external walls* according to the distance between them. However, the nature and location of *fire-source features* presents challenges during the design process. If *fire-source features* were to be included in drawings, stakeholders would need to create many incidental objects (such as roads, rivers or buildings) next to the building being designed. In most cases, stakeholders spend little time creating such surrounding objects. Moreover, roads, rivers and similar objects can only be created as surface objects, which have no specific parameters that distinguish them. These factors all complicate the measurement of the distance between *external wall* and *fire-source feature*.

5.3.2.3.2 Suggested Solutions

Due to the fact that current BIM software cannot provide these *fire-source feature* objects with specific parameters, it was only possible to measure the distance between *external walls* and boundaries of allotments. However, the information relating to the boundaries of allotments provided by Revit is incomplete because Revit can only identify the vertices of the allotment surface. Therefore, additional calculations are required to establish the boundaries. All vertices need to be connected to calculate the boundaries but there must be connections within the allotment that are not boundaries (see the dash lines in figure 5.6). The angles for each two connected lines may then be estimated. The two intersected lines that make the largest angle are determined as the boundaries. For example, the ∠BAE intersected by $\overline{AB}$ and $\overline{AE}$ is the largest (which is larger than ∠BAC, ∠CAD, ∠DAE, ∠BAD and ∠CAE). Therefore $\overline{AB}$ and $\overline{AE}$ are determined as boundaries. Both *external walls* and the boundaries of the allotment respectively are then divided equally in one thousand segments to estimate the minimum distance between them.

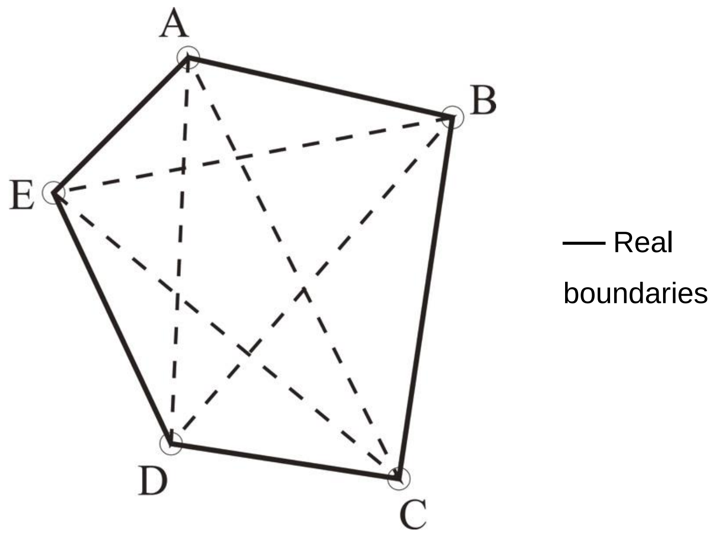


Figure 5.6 Determine the boundaries of allotments

It can be argued that this approach may produce inconsistent results if the allotment is not a convex polygon. A concave polygon may not be calculated correctly (such as the area CDE shown in the Figure 5.7). This may result in the incorrect distance between the *external wall* and boundaries of the allotment. However, an additional constraint incorporated into this approach prevents this. The incorrect estimation of the boundaries may eliminate one vertex (i.e. vertex D in Figure 5.7). A constraint enforcing all vertices to be used can prevent the incorrect estimation and determine the approximately correct boundaries. The only condition that this study cannot address is a curved line that connects two vertices (which is a rare occurrence).

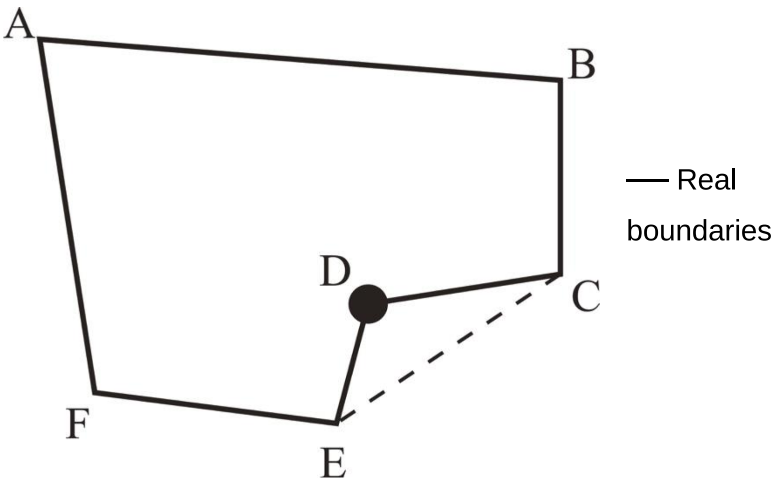


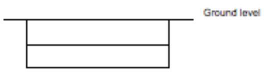
Figure 5.7 Exclude the exceptions for a concave polygon

5.3.3 Examining rules using purpose-based models

Within the development of rule designs, several purpose-based BIM models were created to examine each building code. These models have been created in a simple manner. For example, the model may be a two-storey building that contains one room for each storey. These rooms are tagged with different names to examine the building classifications and the type of construction. These models and the building codes they target are illustrated in Table 5.5 below. These model tests contributed to setting up the prototype of *Ignis* for further evaluation works (described in Chapter 6 at page 112).

Table 5.5 Examining rule designs using purpose-based models

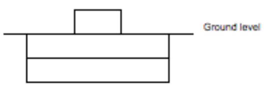
Test #1



Model information			Report		
Floor area (m^2)	Height(m)	Room tag	Building class	Screen	No level above GL
-	-	-	N/A	BC for HAL	N/A
300	2.8	Carpark	N/A	RIS	N/A
300	2.8	Carpark	N/A	Type	N/A

Target Code: C1.1

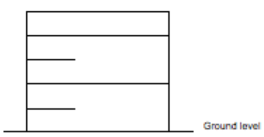
Test #2



Model information			Report		
Floor area (m^2)	Height(m)	Room tag	Building class	Screen	No HAL
60	2.8	N/A	N/A	BC for HAL	N/A
300	2.8	Carpark	N/A	RIS	N/A
300	2.8	Carpark	N/A	Type	N/A

Target Code: C1.1, C1.2

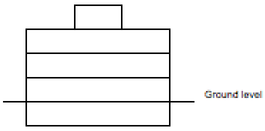
Test #3



Model information			Report		
Floor area (m^2)	Height(m)	Room tag	Building class	Screen	Report is ready
200	2.8	Office	5	BC for HAL	5
66.6	2.8	Office	-	RIS	3
200	2.8	Office	5	Type	B
66.6	2.8	Office	-		
200	3.3	Office	5		

Target Code: C1.2, C1.3

Test #4



Model information			Report		
Floor area (m^2)	Height(m)	Room tag	Building class	Screen	No BC for HAL
60	2.8	N/A	N/A	BC for HAL	N/A
300	2.8	N/A	N/A	RIS	N/A
300	2.8	Shop, Office	N/A	Type	N/A
300	2.8	Carpark	N/A		
300	2.8				

Target Code: C2.1, C2.2

Test #5

Model information			Report		
Floor area (m^2)	Height(m)	Room tag	Building class	Screen	Report is ready
200	2.8	Assisted care, office, toilet	9c, 5	BC for HAL	9c
200	2.8	CNC, kitchen, instruction	9b	RIS	4
200	2.8	Treatment, café, carpark,	9a, 6, 7a	Type	A
200	2.8	Supermarket, carpark, office	6, 7a, 5		

Target Code: C1.2, C2.1, C 2.2, C 2.5

Test #6

Model information			Report		
Floor area (m^2)	Height(m)	Room tag	Building class	Screen	Report is ready
66.6	2.8	Office	5	BC for HAL	7b
200	2.8	Warehouse	7b	RIS	3
66.6	2.8	Office	5	Type	B
200	3.3	Warehouse	7b		

Target Code: C1.2, C1.3 C2.1, C 2.2, C 2.5

5.4 System interface

When users begin with a new computer system, they usually feel frustrated if interfaces are complex (Chin et al. 1988, Gu et al. 2011). Simplicity was thus a necessity of the *Ignis* interfaces. As *Ignis* is embedded in the Revit, an independent tool bar called ‘Code Checking’ was created. A button called ‘*Ignis*’ was then established in the subcategory. This is shown in Figure 5.8. When users click the *Ignis* button, a task menu appears (Figure 5.9). This menu contains three options: building class setup, pre-test and analyse.

The most relevant options for *Ignis* users are building class setup and analyse. Pre-test was used by the researcher to examine and verify rule designs. When a new project is started, users may need to setup room names for the building classes. Once this has been done there is no need to re-setup this table for building class again.

When users press the analyse button, the code-checking activities are commenced. The *Ignis* interfaces are simple and users only need a few clicks and then *Ignis* can produce results. These results may be presented in reports which are discussed in next section.

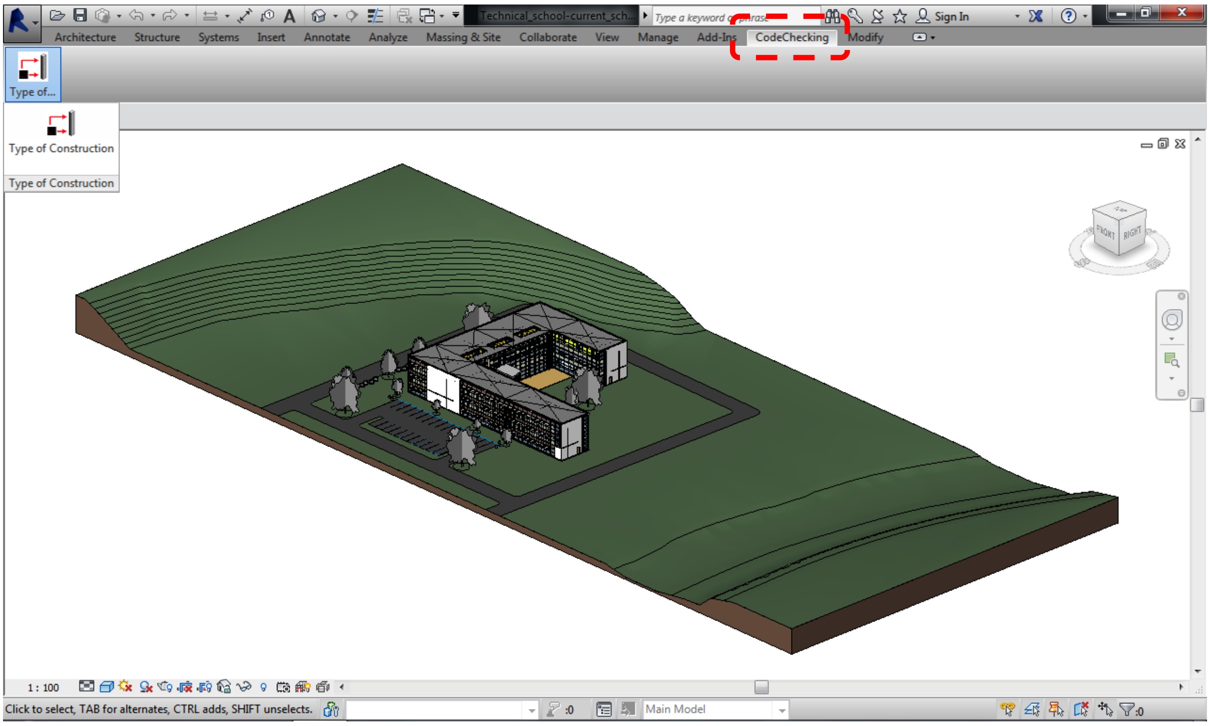


Figure 5.8 Interface layout for *Ignis*

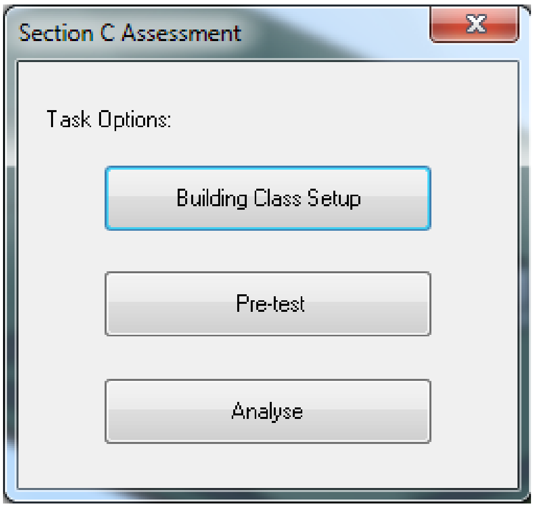


Figure 5.9 A task menu

5.5 Report information

Ignis has been designed to produce reports of assessment results in visual as well as textual formats. Once code-checking activities have been completed, the *Ignis* reports firstly present results in a visualized floating window. These reports can be exported in a pdf files format for printing as textual reports.

Both of the *Ignis* reports present assessment results clause by clause. This follows the formats that are generally used in the project reports created by accredited certifiers. The reports contain 'status' and 'comment' columns. Status columns confirm what 'complies' or 'does not comply' and comment columns indicate the reasons for not compliance. Visualized and textual reports are further discussed with graphics in the following sections.

5.5.1 Visualized reports

As described above, the format of the visualized reports for the *Ignis* prototype refers to practical reports made by accredited certifiers. In addition to the assessment results for each code, the *Ignis* visualized reports provide a number of basic information items as shown in Figure 5.10. The model names and time it assesses are described first. This records the history of the assessments to track the latest code-checking activity and provides an introduction for the activity. The report emphasizes that this assessment has been conducted against the DTS regulations and that alternative methods have not been considered. Moreover, it sets limitations which define the building codes that *Ignis* deals with. Finally, the *Ignis* reports provide basic assessment information regarding the building classifications, numbers of assessable storeys, effective height and type of construction. These provide users with an overall concept of the assessment.

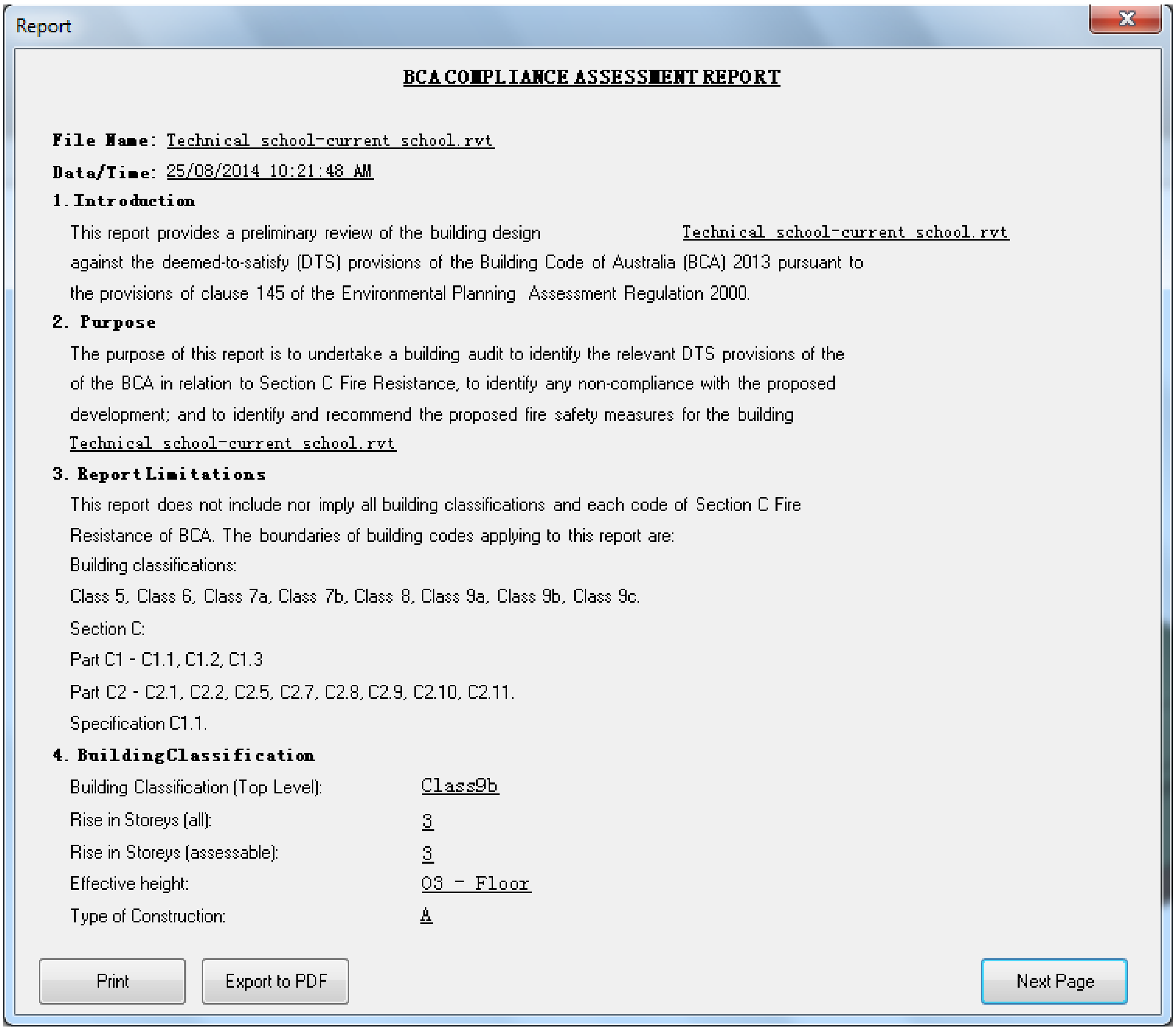


Figure 5.10 Basic assessment information on the *Ignis* visualized reports

This is followed by the assessment results for each building code. The report is primarily formatted in four columns: clause, reference, status and comment (shown in Figure 5.11). The clause and reference describe the code number and topic. The status column tells users whether the building designs comply with this code or not. The comment column describes the reasons for determining whether or not the building complies. Detail information (e.g. object numbers and the level it locates) may also be shown to help users understand how the assessment results have been determined.

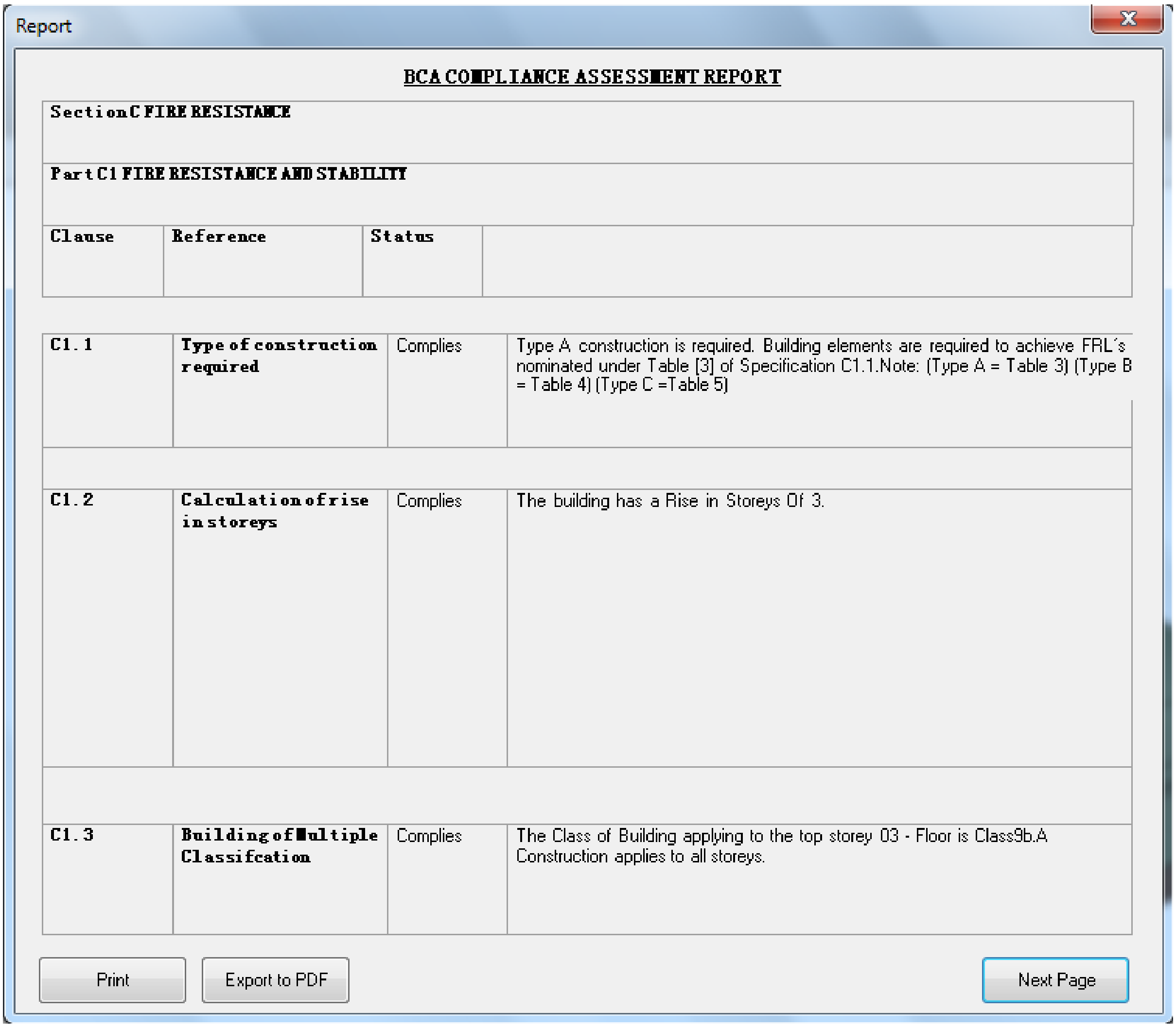
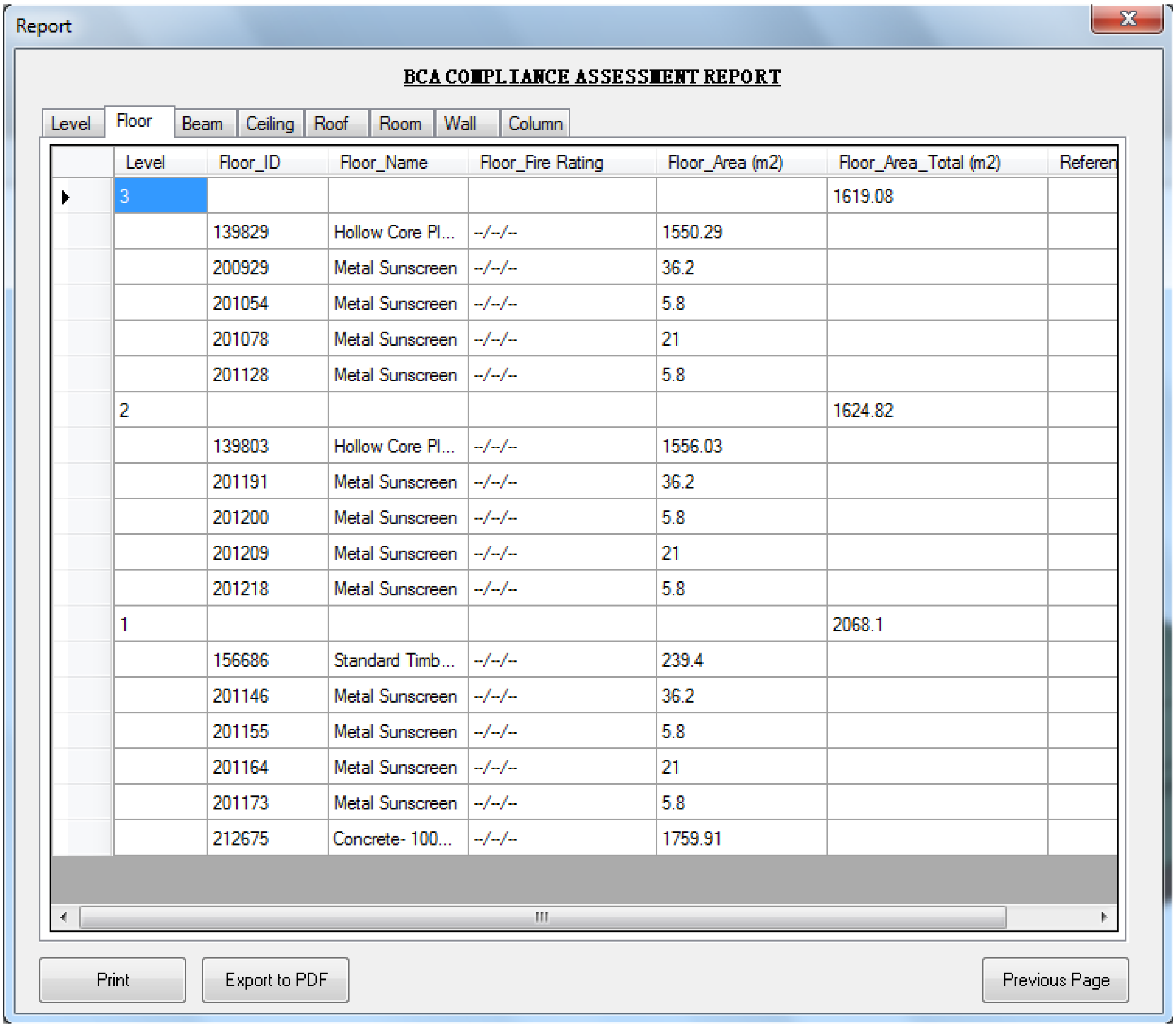


Figure 5.11 Assessment results for each building code

In addition to presenting assessment results clause by clause for part C1 and C2 of Section C, the assessment results for Specification C1.1are presented below. As many types of building elements need to be assessed for FRL, excel-like tables are used to present results. Should the FRL of an object not comply, it is marked in red and users can click these red marks to locate this building element. These tables for building elements (e.g. floors, roofs and walls) are shown from Figure 5.12 to Figure 5.17.



Report

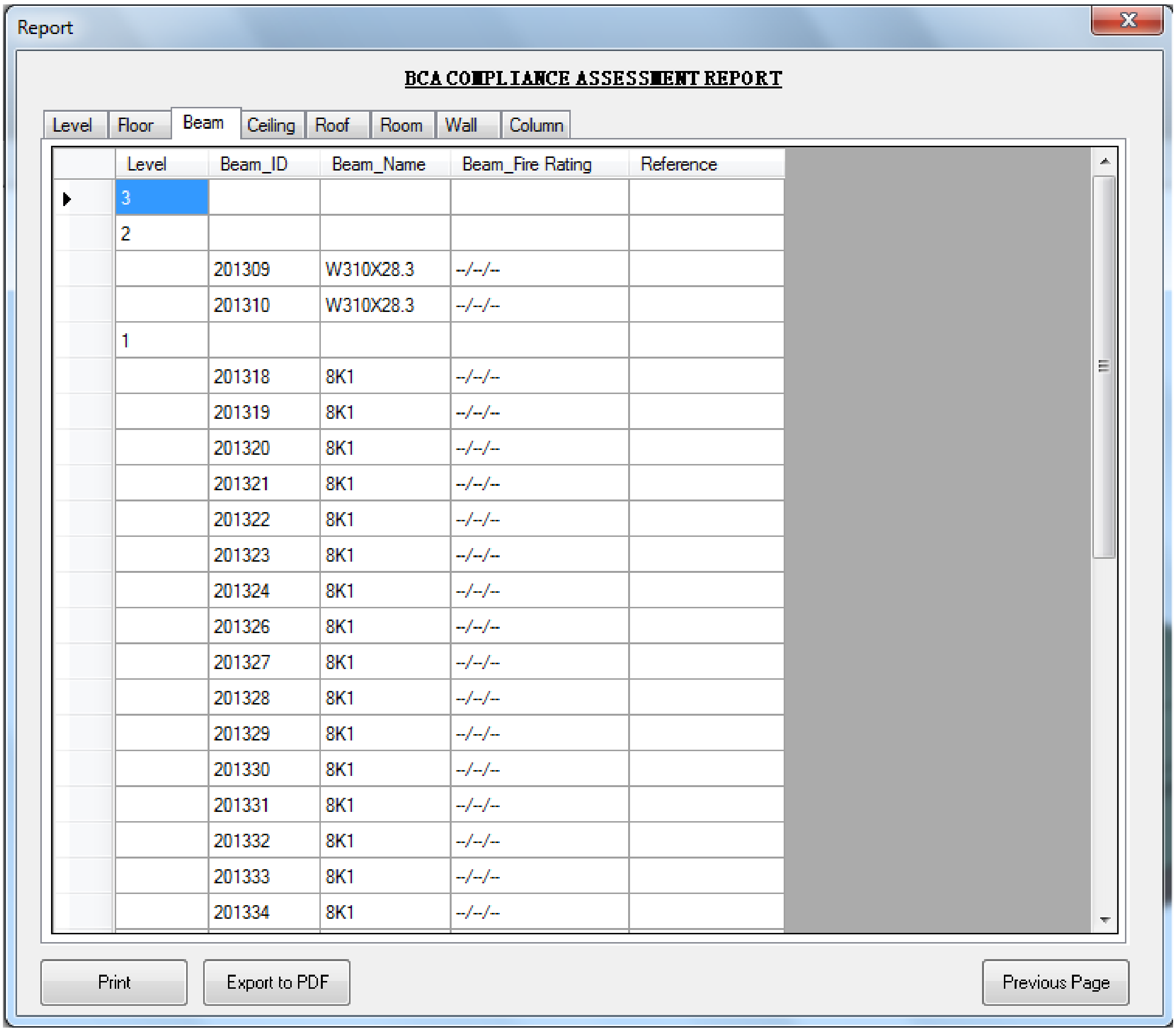
BCA COMPLIANCE ASSESSMENT REPORT

Level | Floor | Beam | Ceiling | Roof | Room | Wall | Column

Level	Floor_ID	Floor_Name	Floor_Fire Rating	Floor_Area (m2)	Floor_Area_Total (m2)	Referen
3					1619.08	
	139829	Hollow Core Pl...	--/--/--	1550.29		
	200929	Metal Sunscreen	--/--/--	36.2		
	201054	Metal Sunscreen	--/--/--	5.8		
	201078	Metal Sunscreen	--/--/--	21		
	201128	Metal Sunscreen	--/--/--	5.8		
2					1624.82	
	139803	Hollow Core Pl...	--/--/--	1556.03		
	201191	Metal Sunscreen	--/--/--	36.2		
	201200	Metal Sunscreen	--/--/--	5.8		
	201209	Metal Sunscreen	--/--/--	21		
	201218	Metal Sunscreen	--/--/--	5.8		
1					2068.1	
	156686	Standard Timb...	--/--/--	239.4		
	201146	Metal Sunscreen	--/--/--	36.2		
	201155	Metal Sunscreen	--/--/--	5.8		
	201164	Metal Sunscreen	--/--/--	21		
	201173	Metal Sunscreen	--/--/--	5.8		
	212675	Concrete- 100...	--/--/--	1759.91		

Print | Export to PDF | Previous Page

Figure 5.12 FRL assessment for floors



Level	Beam_ID	Beam_Name	Beam_Fire Rating	Reference
3				
2				
	201309	W310X28.3	--/--/--	
	201310	W310X28.3	--/--/--	
1				
	201318	8K1	--/--/--	
	201319	8K1	--/--/--	
	201320	8K1	--/--/--	
	201321	8K1	--/--/--	
	201322	8K1	--/--/--	
	201323	8K1	--/--/--	
	201324	8K1	--/--/--	
	201326	8K1	--/--/--	
	201327	8K1	--/--/--	
	201328	8K1	--/--/--	
	201329	8K1	--/--/--	
	201330	8K1	--/--/--	
	201331	8K1	--/--/--	
	201332	8K1	--/--/--	
	201333	8K1	--/--/--	
	201334	8K1	--/--/--	

Figure 5.13 FRL assessment for beams

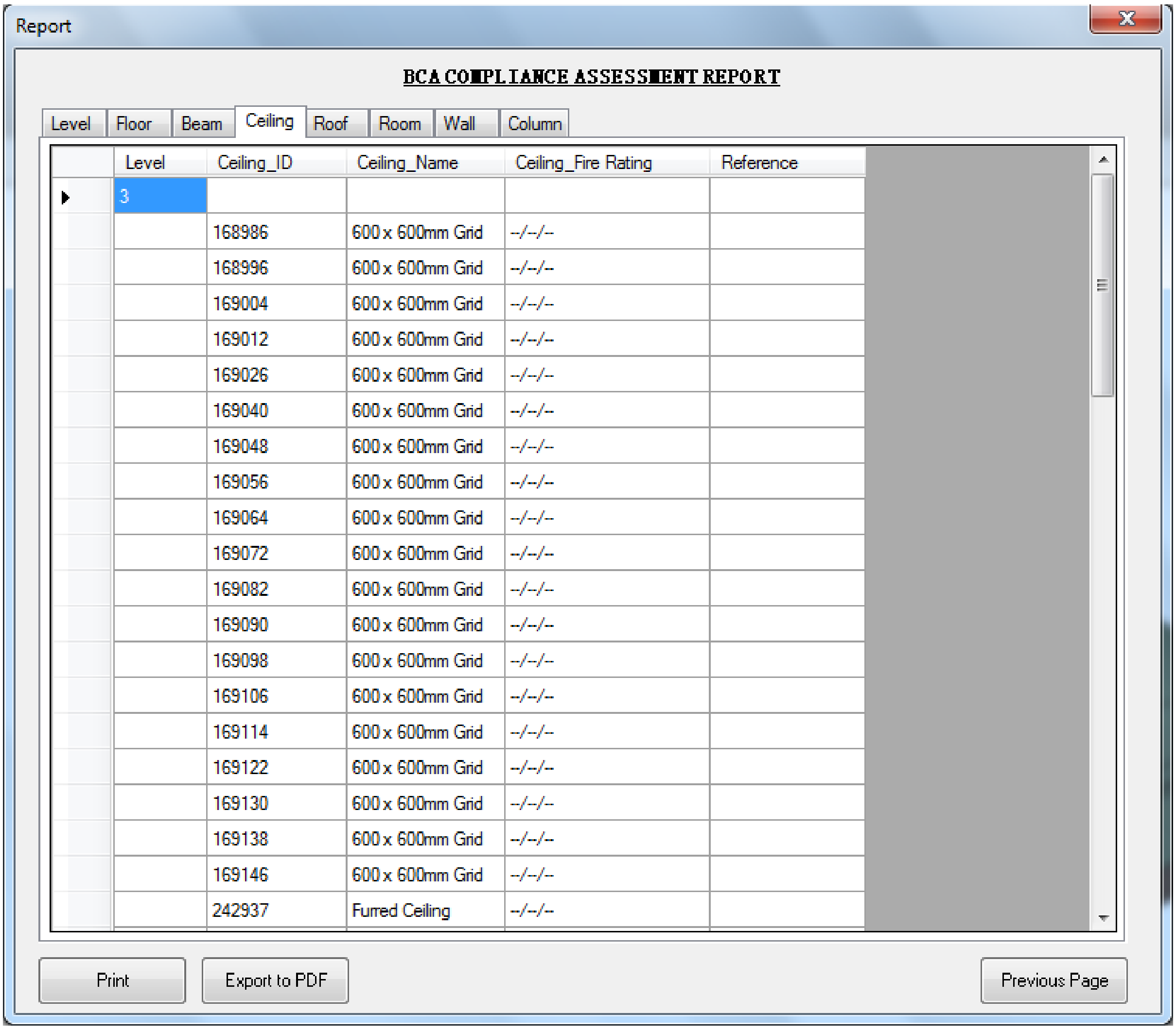


Figure 5.14 FRL assessment for ceilings

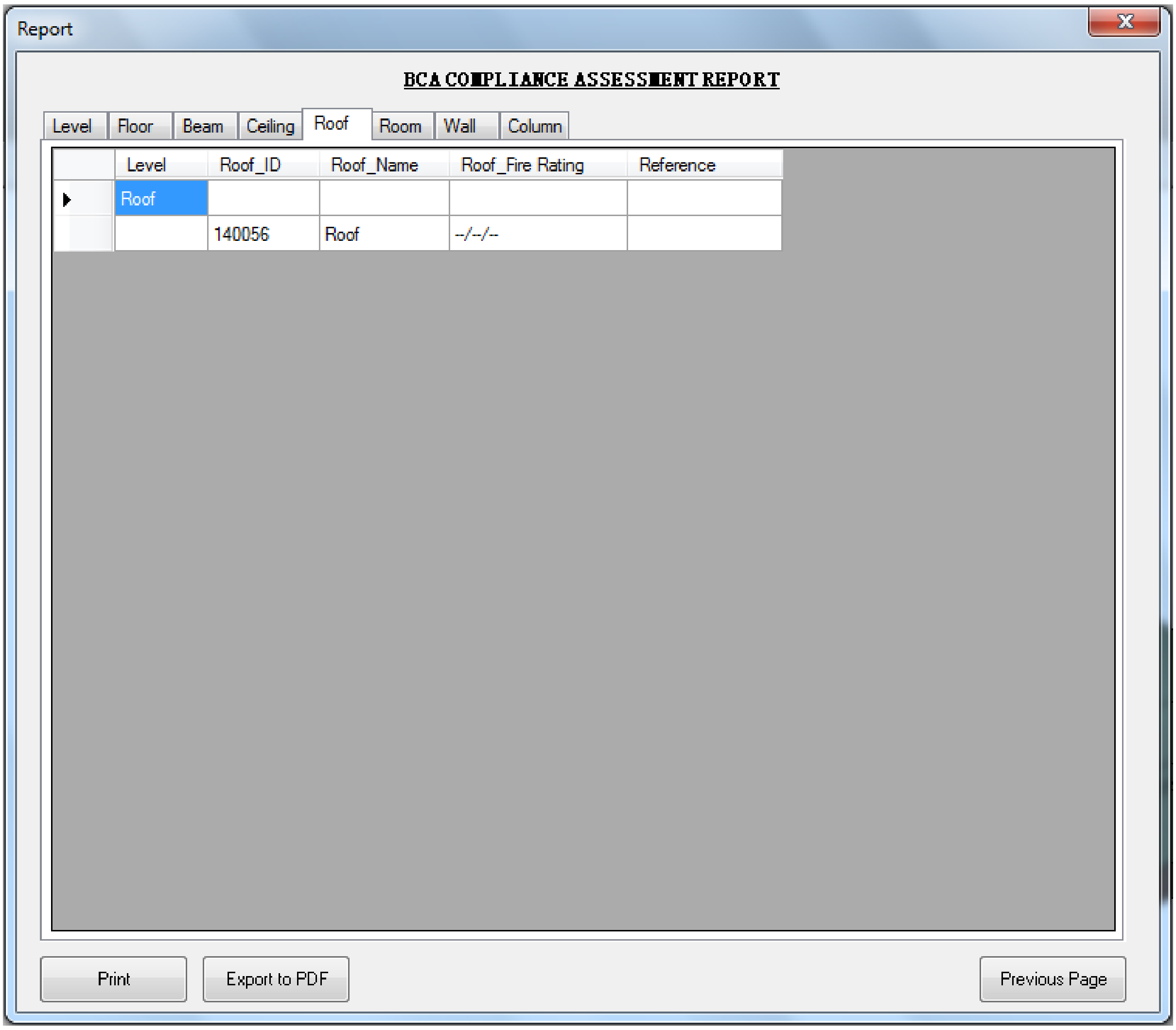
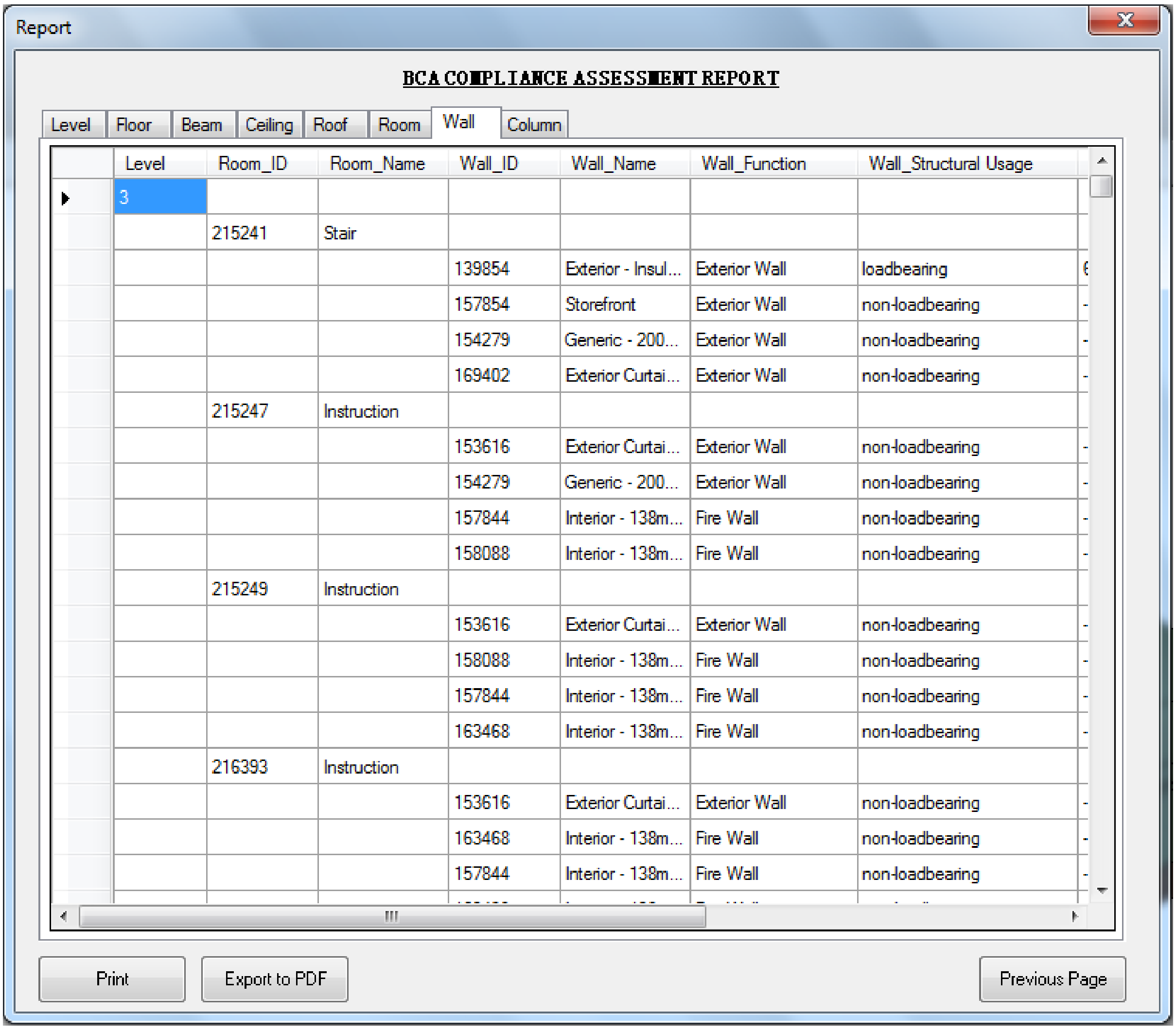
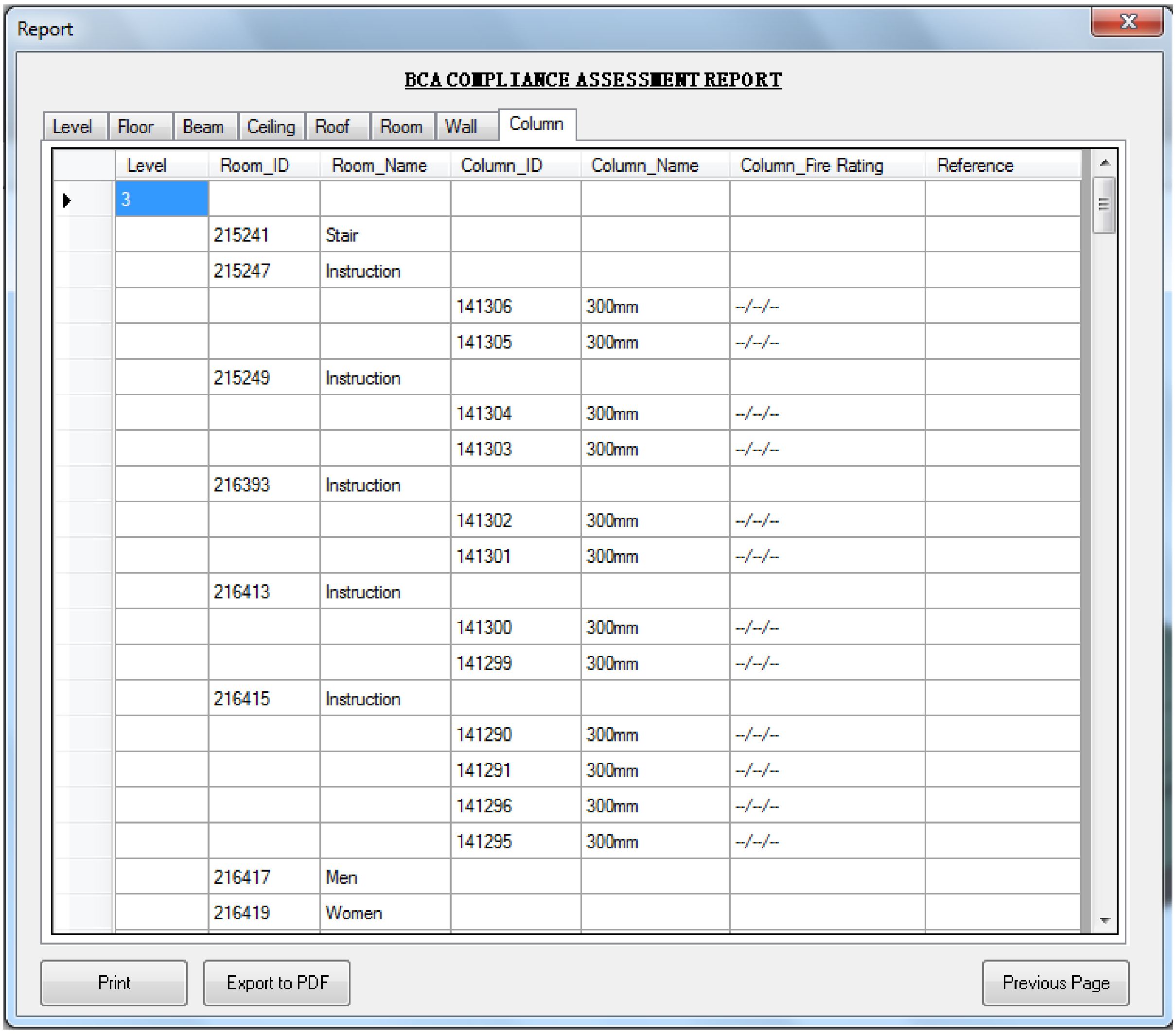


Figure 5.15 FRL assessment for roofs



Level	Room_ID	Room_Name	Wall_ID	Wall_Name	Wall_Function	Wall_Structural Usage
3						
	215241	Stair				
			139854	Exterior - Insul...	Exterior Wall	loadbearing
			157854	Storefront	Exterior Wall	non-loadbearing
			154279	Generic - 200...	Exterior Wall	non-loadbearing
			169402	Exterior Curtai...	Exterior Wall	non-loadbearing
	215247	Instruction				
			153616	Exterior Curtai...	Exterior Wall	non-loadbearing
			154279	Generic - 200...	Exterior Wall	non-loadbearing
			157844	Interior - 138m...	Fire Wall	non-loadbearing
			158088	Interior - 138m...	Fire Wall	non-loadbearing
	215249	Instruction				
			153616	Exterior Curtai...	Exterior Wall	non-loadbearing
			158088	Interior - 138m...	Fire Wall	non-loadbearing
			157844	Interior - 138m...	Fire Wall	non-loadbearing
			163468	Interior - 138m...	Fire Wall	non-loadbearing
	216393	Instruction				
			153616	Exterior Curtai...	Exterior Wall	non-loadbearing
			163468	Interior - 138m...	Fire Wall	non-loadbearing
			157844	Interior - 138m...	Fire Wall	non-loadbearing

Figure 5.16 FRL assessment for walls



Level	Room_ID	Room_Name	Column_ID	Column_Name	Column_Fire Rating	Reference
3						
	215241	Stair				
	215247	Instruction				
			141306	300mm	--/--/--	
			141305	300mm	--/--/--	
	215249	Instruction				
			141304	300mm	--/--/--	
			141303	300mm	--/--/--	
	216393	Instruction				
			141302	300mm	--/--/--	
			141301	300mm	--/--/--	
	216413	Instruction				
			141300	300mm	--/--/--	
			141299	300mm	--/--/--	
	216415	Instruction				
			141290	300mm	--/--/--	
			141291	300mm	--/--/--	
			141296	300mm	--/--/--	
			141295	300mm	--/--/--	
	216417	Men				
	216419	Women				

Figure 5.17 FRL assessment for columns

5.5.2 Textual reports

Once the visualized reports have been created, a button 'Export to PDF' can be used to export textual reports in PDF format. It also contains basic assessment information on the first page describing the file name, time and limitations of the assessment. Then the report follows the assessment results for Part C1 and Part C2, clause by clause. The format of textual reports refers to the practical reports that generated from manual certification works. The first two pages are shown in Figure 5.18 and 5.19 while the full textual reports are provided in Appendix 4.

BCA COMPLIANCE ASSESSMENT REPORT

File name: Technical_school-current_school.rvt
Date/time: 18/09/2014 12:33:01pm

1. Introduction

This report provides a preliminary review of the building design "Technical_school-current_school.rvt", against the deemed-to-satisfy (DTS) provisions of the Building Code of Australia (BCA) 2013 pursuant to the provisions of clause 145 of the Environmental Planning & Assessment Regulation 2000.

2. Purpose

The purpose of this report is to undertake a building audit to identify the relevant DTS provisions of the BCA in relation to Section C Fire Resistance, to identify any non-compliance with the proposed development; and to identify and recommend the proposed fire safety measures for the building "Technical_school-current_school.rvt".

3. Report Limitations

This report does not include nor imply all building classifications and each code of Section C Fire Resistance of BCA. The boundaries of building codes applying to this report are:

Building classifications:
Class 5, Class 6, Class 7a, Class 7b, Class 8, Class 9a, Class 9b, Class 9c.
Section C:
Part C1 – C1.1, C1.2, C1.3
Part C2 – C2.1, C2.2, C2.5, C2.7, C2.8, C2.9, C2.10, C2.11.
Specification C1.1.

4. Building Classification

Building Classification (Top Level):	Class 9b
Rise in Storeys (all):	3
Rise in Storeys (assessable):	3
Effective height:	7.6m
Type of Construction:	A

Page **1** of **7**

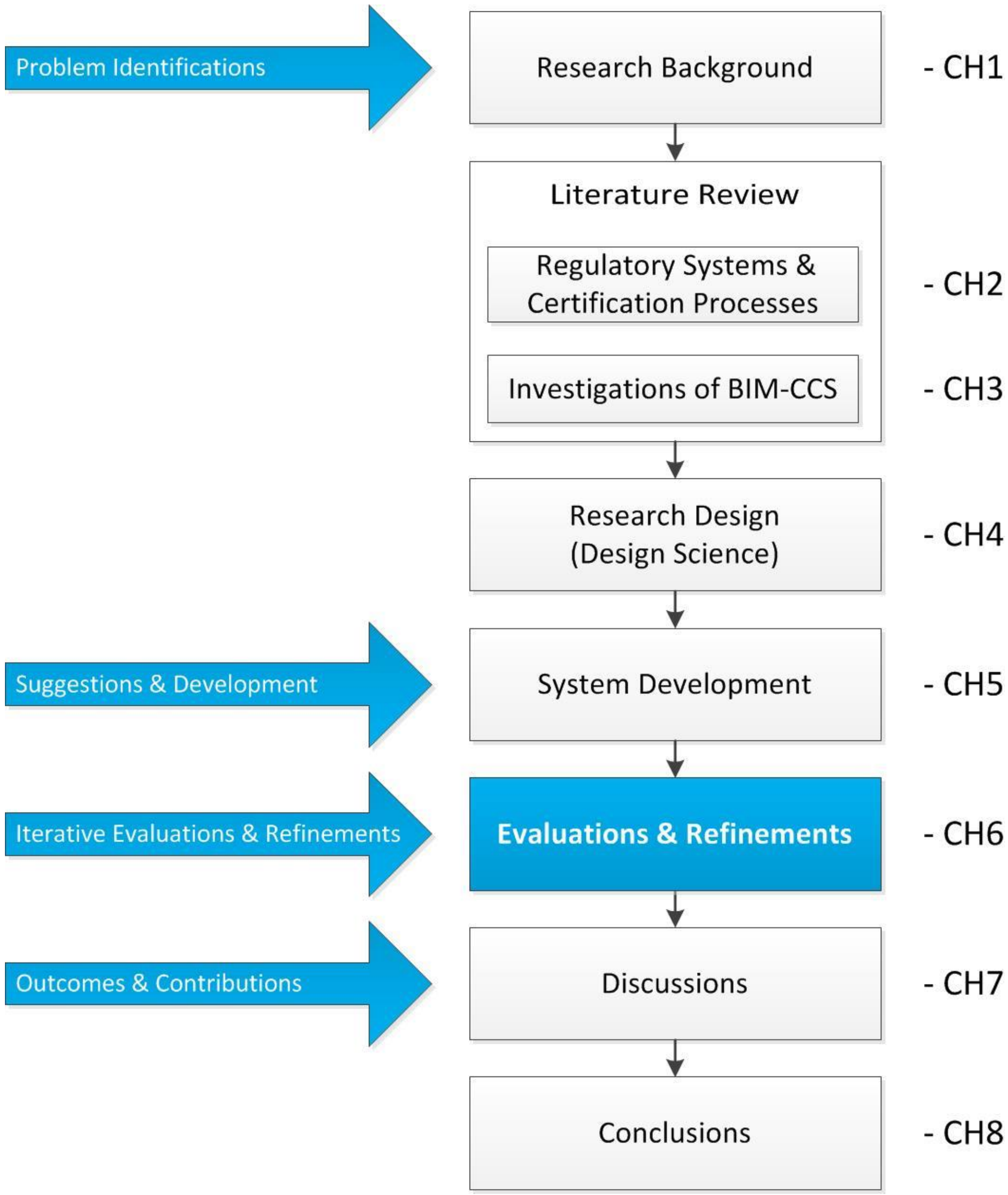
Figure 5.18 Basic assessment information in textual reports

Clause	Reference	Status	Comment
Section C FIRE RESISTANCE			
Part C1 FIRE RESISTANCE AND STABILITY			
C1.1	Type of construction required	Complies	Type A construction is required. Building elements are required to achieve FRL's nominated under Table 3 of Specification C1.1.
C1.2	Calculation of rise in storeys	Complies	The building has a Rise in Storeys of 3.
C1.3	Building of Multiple classification	Complies	The Class of Building applying to the top storey Level 03-Floor is Class 9b. Type A Construction applies to all storeys.
Part C2 COMPARTMENTATION AND SEPARATION			
C2.1	Application of Part	Not Applicable	The building does not contain Open-deck Carpark that are subject to this provision.
C2.2	General Floor Area and Volume Limitations	Complies	The proposed floor area and volume of the fire compartment in the building are within the fire compartment limitations prescribed for Type A construction for the classifications concerned.
C2.5	Class 9a and 9c buildings	Not Applicable	The building does not contain class 9a and / or class 9c compartmentations.
C2.7	Separation by fire walls	Noted	The Fire wall 157807 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor. The Fire wall 157778 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor. The Fire wall 164417 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor.

Page **2** of **7**

Figure 5.19 Assessment results for each code clause

6 EVALUATIONS AND REFINEMENTS



6.1 Introduction

In this study, *Ignis* has been informed by the need to check commercial building designs against Section C of the BCA. *Ignis*' components have been iteratively examined and developed to respond to the BCA requirements using a range of BIM models. Multiple and iterative assessments were necessary to ensure the validity of *Ignis* in a holistic manner. These have been underpinned by Design Science research methodology, highlighting that iterative evaluation and modification are prerequisites of effective artefacts.

The first stage in this process was for the researcher to self-assess *Ignis* using a range of BIM models. The researcher subsequently invited external parties to participate in further evaluations. ABPB accredited certifiers and architects were incorporated into the evaluation processes. Accredited certifiers (research participants) who have expertise in the BCA documents and could determine whether the code-checking rules embedded in *Ignis* were effective. They could also foresee issues that may influence the effectiveness of *Ignis*. Architects (research participants) were the target users of the system and those who took part in this study had strong BIM experience and knowledge. Their input assisted in identifying unforeseen issues.

This chapter describes the evaluation process that was designed in three stages (Figure 6.1). It began with a preliminary evaluation by one accredited certifier. In addition to assessing *Ignis* against the evaluation criteria, the purpose of this preliminary study was to identify any shortcomings of the system and to refine the questions to be used in subsequent interviews. The preliminary results determined whether *Ignis* needed to be modified (as a first version prototype). This was followed by two primary evaluations conducted sequentially with accredited certifiers and architects separately using revised versions of *Ignis*. It was anticipated that *Ignis* might require additional modification depending on the results of each primary evaluation.

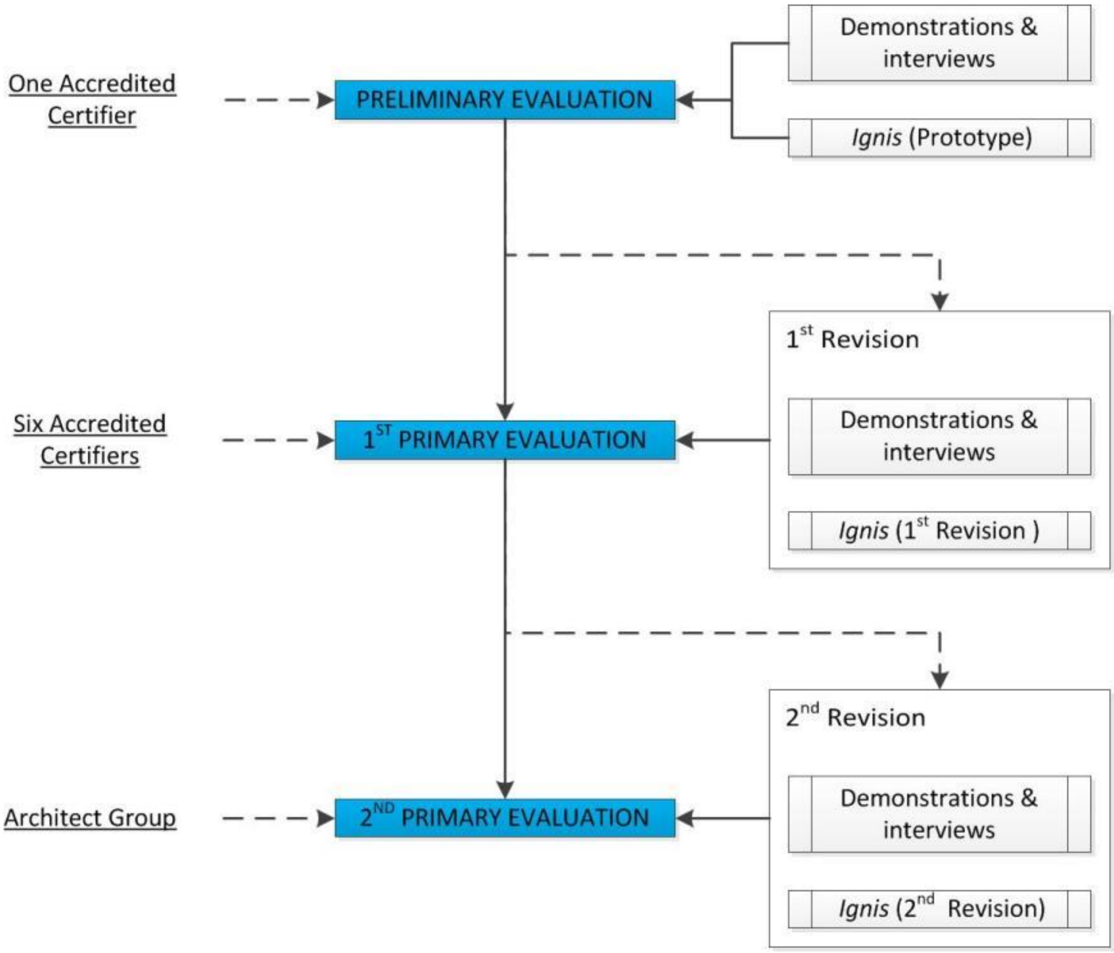


Figure 6.1 Three sequential evaluation stages to examine *Ignis*

6.2 Evaluation methods

The evaluation methods used in the evaluation processes began with a demonstration to research participants and followed by a semi-structured interview (Figure 6.2). The demonstration included two tasks: an explanation of the rules embedded in *Ignis* followed by the testing the *Ignis* system using a sample BIM model provided by *Autodesk*®. The interviews were based on interview questions intended to encourage participants to provide feedback about the manner in which *Ignis* was used.

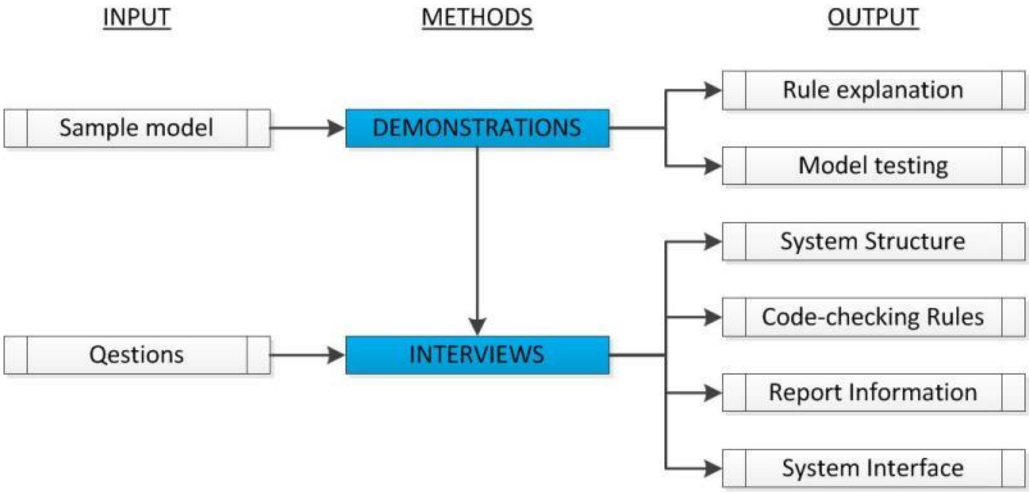


Figure 6.2 Two methods used sequentially in the evaluation process

6.2.1 Demonstrations

The demonstration included a presentation by the researcher during which an explanation was given to domain experts of how *Ignis* interpreted Section C of the BCA. This included, for example, a description of the ways the building class of a building is determined, and an explanation of how the shortest distance from external walls to fire-source features was calculated. This presentation was facilitated by graphs and texts to enhance each participant's understanding (Appendix 5).

A demonstration was then given to research participants of the code-checking activities *Ignis* undertakes using a freely available sample model provided by Autodesk® (Autodesk 2014). This model was for a three-storey school building containing multiple function rooms. Figure 6.3 illustrates this sample model, showing that it consists of multiple building classifications including instruction rooms (class 9b), cafeteria (class 6) and office (class5) rooms. In accordance with the definitions of building classes described in Table 2.4 (at page 20), this sample model was classified as class 9b. This is defined as 'An assembly building, including a trade workshop, laboratory or the like, in a primary or secondary school, but excluding any other parts of the building that are of another class' (Australian Building Codes Board 2013: 42). This model provided a meaningful approach for evaluating the ways in which *Ignis* assesses the fire resistance requirements of the BCA*Ignis*.

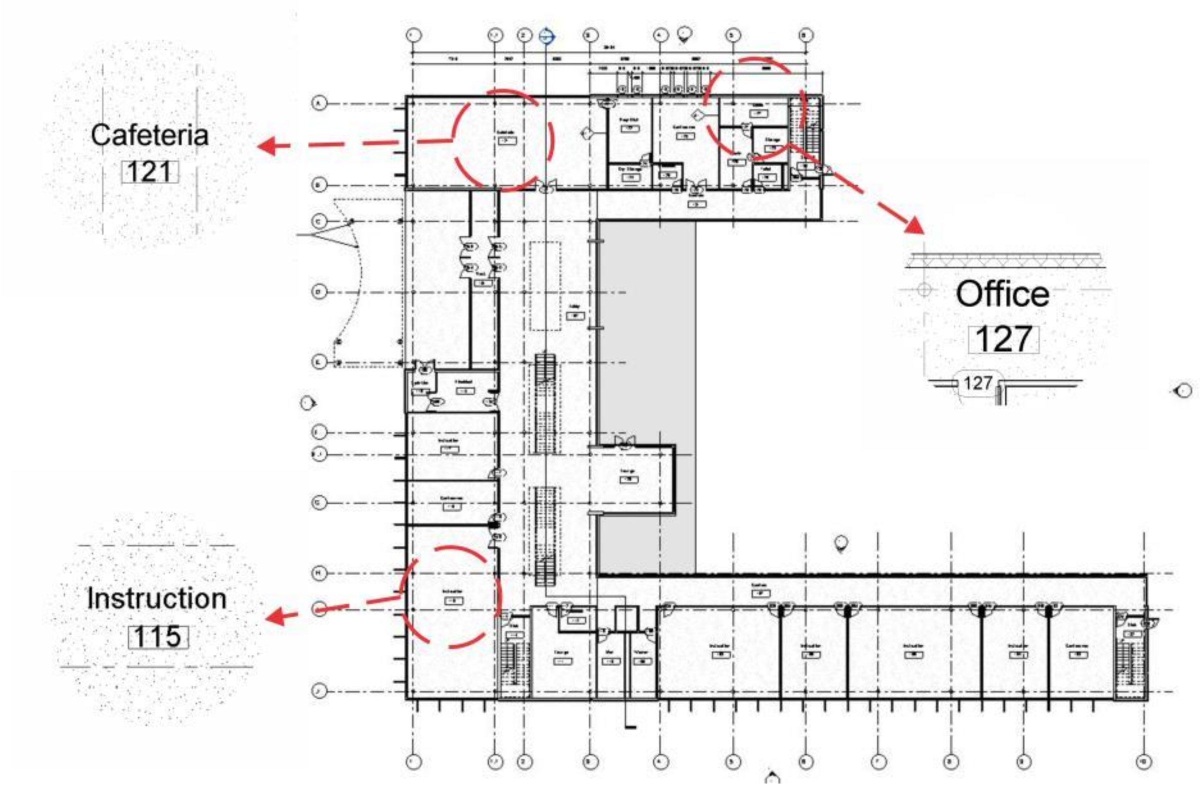


Figure 6.3 Sample model contains various function rooms in the ground level

During the demonstration, the researcher provided participants with printouts of floor plans. Each participant was then asked to review these drawings to develop an appreciation of the instances Section C of the BCA applied to the drawings. Afterwards, *Ignis* was used to assess the sample model for compliance with the BCA. Touch screen facilities were used to allow participants to interact with *Ignis* (Figure 6.4). When the assessment was complete, *Ignis* produced an interactive visual report highlighting instances of non-compliance in red and providing comments identifying key objects and suggestions. The participants were able to easily locate the identified objects. Finally, the visual reports were exported to pdf files (Appendix 4). These enabled the participants to check their understandability and reliability.

The demonstration enabled the participants to understand the manner in which *Ignis* operates. It enabled them to appreciate: (1) how code-checking activities could be incorporated into BIM technology, (2) how the fire resistance codes were interpreted for rule designs, (3) how assessment reports informed whether building designs complied, and (4) how users interact with *Ignis* when conducting code-checking activities. The simulation demonstration enabled participants to comment on relevant issues during the later interview stage.

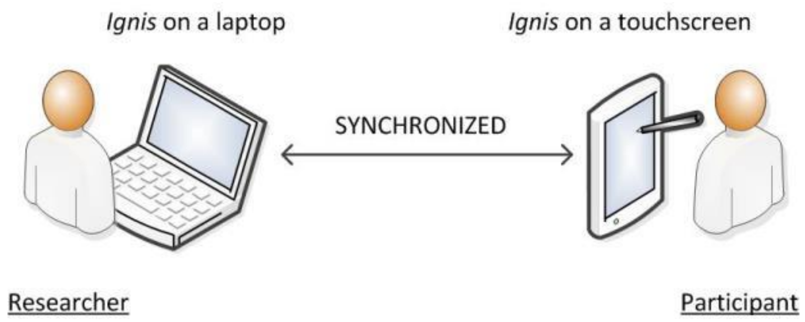


Figure 6.4 Evaluation environmental setting for participants

6.2.2 Interviews

Once the demonstration was finished, participants were invited to be interviewed. These conversations were audio recorded. The interview questions that were used to guide the participants during these interviews are provided in section 4.5.2.2 of Chapter 4 (page 77). These questions were generated from evaluation criteria and presented as twelve specific items. The researcher categorized these items into four topics as summarized in Table 6.1. The detail for each topic has been described in Section 4.6 of Chapter 4 (page 80).

Table 6.1 Evaluation criteria for each topic

Topic	Evaluation Criteria
System structure	Functionality, Better solutions, Impacts on environment and users, Efficiency, Efficacy
Code-checking rules	Consistency, Effectiveness
Report information	Understandability, Reliability, Side Effects
System interface	Simplicity, Usability

6.3 Preliminary evaluation

The purpose of the preliminary evaluation was to examine *Ignis* against the evaluation criteria (Table 6.1). This was conducted with one purposively selected accredited certifier. The interview responses from the certifier assisted the researcher in determining whether the interview questions needed revising. The background of the participant and the interview results are described in the following sections.

6.3.1 Participant

In the preliminary evaluation, an ABPB accredited certifier was purposively selected and invited to participate to evaluate the first *Ignis* prototype. This participant was accredited in the top certifier grade (A1) and had been certifying building projects for the past 18 years in a local council. The participant had a structural engineering background and had experience of BIM-related technologies. This highlights that the participant had a basic understanding of

BIM technology, in addition to his expert knowledge of the BCA. The participant thus had the abilities and knowledge to assess *Ignis* in a comprehensive manner.

6.3.2 Evaluation results

Twelve questions were asked, categorized in four topics (Figure 6.2): system structure, code-checking rules, report information and system interfaces. The answers to each topic are discussed in the following sections.

6.3.2.1 System structures

The structure of *Ignis* highlights the connection of two concepts: BIM and code checking. At present, in the Australian building industry, few tools are available to assist stakeholders assess building designs for compliance with fire resistance codes during the design process (described in Section 3.6 at page 44). The *Ignis* structure was seen as providing a viable solution. The participant acknowledged that *Ignis* could reduce the time stakeholders (as well as certifiers) took to check that drawings complied with the requirements of the BCA as the following quote shows.

> ‘It would be extremely useful...it gives the designers an immediate response as to whether it will comply or not in the design process. So it would, I imagine, cut out a lot of time wasting, because they’re not progressing with something that won't comply when it gets to the certifier...if they use this type of system, when I receive the drawings they would have been probably 90 %, or even 100% complete and correct... I'd like it to be available to certifiers as well so they can do their own check on it very quickly.’

This participant agreed that the way *Ignis* implemented code-checking activities in the BIM environment was useful. He identified that project stakeholders and/or certifiers needed to recognise that effective assessments significantly relied on whether the parameters of BIM models were accurate. The participant said

> ‘I would say that, when we assess a building, we’ve got to be 100% sure that the information you put in is absolutely exact. If this system can actually generate that, then measure it and indicate it, then that’s effective.’

The accuracy of the BIM parameters obviously determines whether the results of an assessment are accurate or not. However, project teams needed to revise their designs throughout the design process, and it is difficult to ensure the accuracy of models in every stage of the design process. *Ignis* highlights instances of non-compliance in red in reports, enabling stakeholders to readily identify such issues. This helps stakeholders revise parameters for subsequent code-checking activities in *Ignis*. This iterative sequence underpinned the purpose of this study - using a BIM-CCS (*Ignis*) to assist stakeholders in assessing and modifying building designs during the different stages of design.

6.3.2.2 Code-checking rules

Interpreting BCA clauses so that they could be developed into code-checking rules was the core task of creating *Ignis*. Rules for assessing building designs need to be consistent and effective. The participant was informed about how *Ignis* interpreted code clauses in two ways. Firstly, during the presentation, an explanation was given of the ways code clauses were interpreted. Secondly, the participant could check the sample model (provided as 3D models and 2D drawings) and the reports produced by *Ignis* (in both visual and textual formats). The participant said

> ‘According to my explanation for the code clauses, do you think they follow the rules you usually do in manual certification works?’ (researcher)

> ‘Yes, they do. They are basically following the same principle (as I used).’ (participant)

The participant acknowledged the effectiveness of the *Ignis* rules. It was noted that it could assist users in understanding whether their designs complied or not. The participant said

> ‘The system is actually reading the BCA for you and telling you what clauses apply... It’s giving the user an instant recognition of where he’s going.’

> ‘It’s more effective. You put in the parameters and it tells you whether it’s right or not’

The rules created in *Ignis* were verified by the participant in this preliminary study. However, *Ignis* only focuses on Section C of the BCA. It is conceivable that unforeseen issues relating to interpreting code clauses for rule designs exist in other sections. This is highlighted in the following quote.

> ‘The only problems are at the moment just with fire safety isn't it? Would you be developing this towards other sections, such as sanitary accommodation and stuff like that? You may find out problems there when you look the BCA as a whole.’

6.3.2.3 Report information

When code-checking activities are complete, *Ignis* can produce visual and textual assessment reports. Visual reports enable users to interact with the assessment results. For example, it can highlight the locations of specific objects when users click on object numbers listed in the reports. This enables users to revise their designs forthwith.

> ‘Visual of that yes it is impressive, as I've said, looking at that drawing and looking at that (visualized) report, you can see which object it’s related to…’

> ‘In terms of design requirements, to actually know which walls require what fire-resistance level and where they don't require is important. I think this visualized report for this is good because they can check the location.’

The *Ignis* textual reports were designed to reflect various practicable templates. The report template was intended to reduce ambiguities. Each code clause listed on the reports has ‘status’ columns indicating whether building designs comply or do not comply, and ‘comment’ columns describing reasons for the status. However there is no standard report template that accredited certifiers can refer to in the NSW building regulatory system. Some accredited certifiers do not indicate the status for each clause but provide a conclusion for the whole report instead. The participant described the ways reports are produced in the following quotes.

> ‘That’s the format we use is very similar (to your report format)... I list every clause in the BCA reports basically… but I just put comments against those which are applicable to a particular job...’

> ‘What I do is I put the clause and then just give a comment... at the bottom (of the report) I conclude complies or do not comply. ’

Accredited certifiers often create reports which indicate the part of a building which does not comply with specific building clauses. They do not suggest how developers might amend their designs to comply with the clause(s). This is due to a fact that certifiers are not authorized to inform developers how to solve instances of non-compliance. Should this occur, conflicts of interest might arise between certifiers and developers. *Ignis* has the potential to mitigate this issue. The *Ignis* reports determine ‘status’ (complies or do not comply) and provides detail ‘comments’ for each clause. This may improve users’ understanding of instances of non-compliance and thereby help solve them. The participant argued

> ‘As a certifier, if I'm doing the certification as well I can’t tell them how to do it. All I do is to indicate if it complies or it doesn’t, but they’ve got the clause there to reference back, to see why it doesn’t. But they usually phone me up and say what’s

> wrong and I'll tell them. In writing you can't tell them, because it's a conflict of interest.'

Although *Ignis* reports 'status' differently to the way the participant was used to, the participant agreed that the *Ignis* reports produced effective results for users. The participant stated

> 'If I had this checking system, online computer, instead of having to go through, I mean you can tell at a glance, because it's four storeys or three storeys. It's going to have to be a certain type of construction. That report verifies that. So anything in that report which can clarify something which I'm not sure of. Without having to check everything, if you've got it there as an indication straight away, it's good.'

However, the textual reports produced by *Ignis* may omit information the participant usually adds in his reports. The participant indicated that the basic information for each storey such as floor areas and volumes is necessary. The participant indicated that

> '…which you've given there, and in your report, would your reports include floor areas and volumes and things?' (participant)
>
> 'No, I don't find they are necessary, because the referred reports do not provide these information.' (researcher)
>
> 'I think it is necessary in terms of identifying whether it does comply with the table, like C2.2. So if you gave down here a maximum fire compartment size, people would just check that straight away.' (participant)

As mentioned above, no standard report formats are specified in the NSW regulatory system. Although the aforementioned issue identified by the participant is not included in the *Ignis* report templates, adding information to these reports enables compliance issues to be clarified in a straightforward manner. The first revision of *Ignis* involved the addition of information for each storey on the reports. This was completed before the main evaluation.

6.3.2.4 System Interfaces

The ways *Ignis* operates only requires users press the 'Analyse' button (Figure 5.9 at page95). A report can then be produced. As people may become frustrated when they begin to use new technologies, ease of use was a prime consideration in developing *Ignis*. Users, whether stakeholders or certifiers, may not have used BIM-related technology before. Therefore reducing complex procedures and allowing them to commence code-checking activities is important. Although participants may have BIM-related knowledge, they may have had few experiences of using BIM technology. Through the simulation, the participant was provided with opportunities to use *Ignis* to produce textual reports and interact with the visualized reports. The participant described this process as follows

> 'I wouldn't think it is difficult to use, because I mean once you become used to a system, most of these systems are self-explanatory, and there's a gradual process aren't there that you follow…From what I've seen, I mean I have operated it, I've just pressed a key and brought up different tables and things like that, which is good.'

6.3.3 First revision of *Ignis*

From this preliminary study, the participant identified the absence of report information relating to basic floor areas and volumes for each storey. These provide users with a clear picture of building designs. They provide basic information that may involve many clauses of the BCA, including limitations on floor areas and volumes. The prototype of *Ignis* was therefore revised. The process adopted was underpinned by Design Science methodologies and focused on an iterative process: evaluations and modifications. Figure 6.5 shows the *Ignis* reports before revision while Figure 6.6 illustrates the revised *Ignis* reports, showing that the information of floor areas and volumes has been added. The revised *Ignis* was then used for subsequent evaluations.

4. Building Classification

Building Classification (Top Level):	Class 9b
Rise in Storeys (all):	3
Rise in Storeys (assessable):	3
Effective height:	7.6m
Type of Construction:	A

Figure 6.5 The original *Ignis* reports

4. Building Classification

Building Classification (Top Level):	Class 9b
Rise in Storeys (all):	3
Rise in Storeys (assessable):	3
Effective height:	7.6m
Type of Construction:	A

Storey	Floor area (m^2)	Volume (m^3)
03-Floor	1550.31	4340.85
02-Floor	1556.05	4347.34
01-Entry Level	1759.93	4927.80

Figure 6.6 The revised *Ignis* report

6.3.4 Summary

The purpose of the preliminary evaluation was to examine whether *Ignis* met the evaluation criteria. The responses from the participant informed the evaluation criteria and therefore the evaluation methods that were then adopted in the next evaluation stage. The feedback relating to the four evaluation criteria are summarized below.

In terms of structure, the participant expressed interest in incorporating code-checking rules into a BIM environment. He appreciated that *Ignis* allowed stakeholders to commence code-checking activities during the design process. The participant observed that using *Ignis* should enable stakeholders to ensure that their building designs conformed to BCA requirements before these were lodged with certifiers. He noted that this should reduce time being wasted during certification processes.

Code-checking rules are the core component of *Ignis*. The demonstration to the participant showed how the rules were designed in accordance with the fire resistance code clauses of the BCA. The participant acknowledged that *Ignis* was an effective way of assessing BIM designs against Section C of the BCA. However, the participant also noted that *Ignis* may encounter unforeseen issues when exploring other sections of the BCA.

The assessment reports produced by *Ignis* are provided in both visual and textual formats. The visual reports provide interactive feedback to users, identifying the locations of the specific objects that do not comply. The textual reports replicate the formats that the participant normally used. A significant difference between the report formats is that the *Ignis* reports determine whether each clause complies or not, whilst the participant generally presented his results at the end of his report. It was noted that there is potential for a conflict of interest between certifiers and developers to exist. Certifiers are not allowed to instruct developers how to solve design issues. This highlights that the *Ignis* report comments may enhance users' understanding about BCA clauses. However, the participant suggested that these reports lack information about floor area and volumes for each storey. This shortcoming was addressed in a revision of the *Ignis* report system.

The participant agreed that it was very simple to get used to the *Ignis* system. He observed that it had straightforward interfaces and that users could obtain assessment reports by one click. Furthermore, *Ignis* allowed users to interact with visual reports. These connect to BIM objects and can highlight specific objects that users need to locate. All in all, this preliminary simulation and interview provided feedback that was used to modify the system so that further evaluation could occur.

6.4 First primary evaluation – accredited certifiers

Within the context of Design Science research, *Ignis* needed continuous and iterative evaluations. A primary evaluation was then conducted in the wake of the preliminary study (Figure 6.1). *Ignis* had been examined and verified using a range of BIM models and an accredited certifier. However, engaging additional participants in the primary evaluation processes could further confirm the efficacy of *Ignis*. The first primary evaluation involved six accredited certifiers examining *Ignis* against the four topics (structure, code-checking rules, reports and usability) used in the preliminary study. The evaluation process (including demonstrations and interviews) used in the primary evaluation was verified and underpinned by the preliminary study. The background of the participants and the results of their evaluations are discussed below.

6.4.1 Participants

The ABPB website provides a database where researchers can look for accredited certifiers. This was used to identify participants for the first primary evaluation. The database provided certifiers' information including their gender, accreditation categories, locations and their contact email and phone numbers. This enabled the researcher to contact certifiers working in NSW. Thirty-two accredited certifiers were invited through either emails or phone calls. Six were selected to assist based on their desire to participate in this research.

The basic information for each participant is outlined in Table 6.2. It was noted that the six participants contained one female and one council certifier. In terms of their grade of accreditation, three were rated at A1, one at A2 and the rest were A3. The female certifier had the least certification experience (four years) whilst the others had longer certification experience, ranging from twelve to forty years. Three participants had worked on BIM and/or had BIM related knowledge. Participant #1 and #3 were graduates from architecture-related disciplines. During their study, they had participated in BIM-related courses and had experienced using BIM tools. Participant #6 was employed as a consultant in a building design company that employed approximately eight architects and engineers in total. This company worked on many building projects and participant #6 had extensive experience of discussing design issues on BIM models with stakeholders. They used several BIM tools including as Revit, ArchiCAD and Tekla in their design processes. This shows that three participants had strong experience of using BIM and knowledge about how BIM was used in the design process.

6.4.2 Evaluation results

The six accredited certifiers participated in the evaluations separately. The evaluations followed the procedures used in the preliminary study. The simulation and interview were conducted sequentially. The only one difference to the preliminary study was that the revised *Ignis* (the 1st version) was used instead of the prototype. Feedback on the twelve interview questions was analyzed against the four topics used in the preliminary study: the system structure, the code-checking rules, the report information and the system usability.

Table 6.2 Background of participants for the first primary evaluation

	Gender (Female/ Male)	Accredited Type (Council/Private)	Accredited Category (A1~A4)	Certifying Experience (Years)	BIM knowledge (Yes/No)
Participant #1	Female	Private	A3	4	Yes
Participant #2	Male	Private	A1	38	No
Participant #3	Male	Council	A3	12	Yes
Participant #4	Male	Private	A2	40	No
Participant #5	Male	Private	A1	42	No
Participant #6	Male	Private	A1	27	Yes

6.4.2.1 System structures

The *Ignis* structure involves two concepts, BIM and code-checking. Simulations demonstrated how the 1st version *Ignis* incorporated code-checking activities into a BIM platform (Revit). *Ignis* reads and/or produces parameters in accordance with model information and then applies the parameters to code-checking rules. Assessment results are then produced indicating whether building designs comply or not. *Ignis* may thus affect the ways buildings are designed and certified. It has the potential to impact on the ways in which buildings are designed for compliance. The responses to the *Ignis* structure were positive as participants appreciated *Ignis* connecting BIM and code-checking. Two participants said

> ‘Integrating BCA checks with BIM would be very useful, especially for designers. They might get the red writing on their report and I don't have to answer the question.

It's likely I've spent an hour with the designer and the design team, and figured out those issues in red need to be addressed. They can then tap it in themselves and change their drawing. Then he can get back to me when it's just saying comply… They'll be more efficient and I'll be more efficient because I don't have to answer their questions all the time. I reckon it would be a handy tool.' (Participant #6)

'It's very useful. When it's referring to the plans there, where that was like the cafeteria, a building class 6 there, it can fully determine. So you'd be able to make a better judgment on what fire safety requirements you'll need. So I think it'll be a very useful system.' (Participant #3)

They also mentioned that using *Ignis* in the design process could bring both project stakeholders and certifiers straight to problematic issues and thereby solve them efficiently. Much manual certifying work involves time-consuming calculations which computer extensions can perform in a speedy and accurate manner. The following quotes describe their agreement about this.

'Because a lot of the ground works with doing a BCA assessment is doing the floor area calculations and all that other stuff at the front. So you can then determine what type of building, what classification and all that stuff. What the floor area limitations are and that sort of thing, whether you need fire hose reels or fire hydrants. It's all that calculation stuff and if this does all that ground work up front that's going to save a lot of time because you've got that information ready at hand.' (Participant #4)

Participants highlighted the need for BIM-CCSs in the current Australia building industry and that little effort had been devoted to BIM-CCS to date. They welcomed the fact that *Ignis* could assist project stakeholders to assess their designs for compliance with the BCA codes in multiple stages throughout the design process. This echoed the research aim of this study. They said

'I think it will be handy. I suppose, because this system had highlighted rating issues or deficiencies. We haven't done this in Australia yet. We need to go and do that now. That might help them in the process of the stages of design. So you can probably run at an early stage and at the end for the certificate.' (Participant #3)

'… say a design, initial design concept, is done at this stage and it's probably benefit using this system for the checkers and the designers is they can probably get their concept, get it checked and then it highlights all over the place.' (Participant #6)

Moreover, they appreciated that *Ignis* produced reports quickly. *Ignis* only requires a few seconds to produce a report whilst manual certifying approaches require hours or days. Once users receive assessment results, they can easily revise their designs on the same platform in a straightforward manner. They indicated

> ‘The time it takes to actually assess it would be extremely fast, it would be a big benefit.’ (Participant #3)

> ‘It looks pretty good. I don't think there's going to be too - like I love this stuff, it seems to be easy enough to use to get [generated reporting]. so you can always refine things directly’ (Participant #3)

In addition to assisting with design compliance issues, the concept of BIM-CCS highlighted an issue between stakeholders and certifiers. They acknowledged that certifying authorities were not involved in design processes and that stakeholders could not verify that their designs complied with the BCA before these were lodged. They agreed that this gap potentially could be mitigated by BIM-CCSs. They also highlighted that should BIM-CCSs (like *Ignis*) be implemented in the building industry, the building environment (including design and certifying activities) could be changed.

> ‘I think it's a great idea. I'm familiar with ArchiCAD. You have objects and you're not just working with lines, but you have no abilities to check your designs against the BCA in the design process. This is definitely a gap…this (*Ignis*) is taking it to a whole new level, because certifiers are behind on this, so it (*Ignis*) would be great. This totally changes the whole game of it really.’ (Participant #1)

Notwithstanding these positive responses, the participants identified several issues as described below. The first issue related to the accuracy of BIM parameters. If a BIM parameter is not correct input, it may cause errors and misinform the requirements of code-checking rules, resulting in inaccurate results. Moreover, although some parameters (e.g. fire walls) can be produced by *Ignis*, some abstract parameters (e.g. exits) are difficult to define. The participants said

> ‘This is only going to be as good as the data put into it, like anything. People could put in wrong dimensions or measure it wrong or not understand. As long as the person who's putting the BCA information into this knows what it means.’ (Participant #5)

‘To do a BCA compliance check, there needs to be some pre-requirements for detail in the model. Certain things are missing then the answers may not come forward or they may be coming out wrong. So that will be, I think I see that as probably your main problem.’ (Participant #2)

‘You're extracting information which is I think largely about physical elements of the building, whereas there’s some more conceptual things that come in around things like exits and the like. If in BIM say that opening there doesn’t have any special characteristics that identify it as an exit and you’re doing an analysis. You can’t really appreciate that from the model.’ (Participant #2)

It is relevant to note that up until recently the BCA was revised annually. Since 2015 the ABCB has decided to prolong the period between revisions to three years. Nevertheless, the constant revision of clauses is potentially problematic because *Ignis* would need to be revised. A participant said

‘I think the only problematic thing for this is the constant updates to the BCA… the ability to constantly update their programs and keep up with the changes of the BCA.’ (Participant #3)

However, the aforementioned problems are outside the scope of this study. These issues require discussion between multiple parties including BIM vendors and legislative authorities. Once agreement is reached, a fully-functional BIM-CCS may be successfully developed and implemented. This has the potential to not only provide consistent assessments for building designs but also to avoid human error in certifying activities. A participant forecast the future as follows

‘if you're using your system, it would possibly streamline it a bit, but it could systemise what certifiers did, so if we were using in this office, there's another two or three certifiers here besides me and if we all used this, then we'd have a consistent sort of data that we all understood for a job. So I would think that it would be an improvement in that sense.’ (Participant #5)

A participant highlighted that *Ignis* fits with the strategies in the ABCB instalment plan (Australian Building Codes Board 2014). This plan has identified that incorporating technology into regulatory systems will be a priority task. BIM-CCSs like *Ignis* may be able to inform the future development of the ABCB’s plans. The participant highlighted

> ‘The timing is very good… You realise the building code from next year, the building code will be free but it's also only going to be available digitally. So we're all moving towards these sorts of things. So the idea of the modelling is probably going to fit in well with that new world. Maybe not for certifiers of my age bracket, but for the next generation who will be more familiar with doing all this stuff off a screen as opposed to bits of paper and books. (Participant #5)

6.4.2.2 Code-checking Rules

The code rule designs were verified in the preliminary study. Therefore, in this stage, rule designs were not revised. The preliminary study verified that participants understood the ways code clauses are interpreted to create code-checking rules. The same approaches were used for the six participants in the first primary evaluation. The participants acknowledged the effectiveness of the *Ignis* rules and said

> ‘If the checking procedures follow those you usually use when checking building designs? (Researcher)
>
> Yeah I think so. When I saw that I thought that's exactly what I do.’ (Participant #4)
>
> ‘The processes or the procedures we'd check for compliance, they're the same… I think this would be very affective, extremely affective. It has a lot more information and if you followed down the list of even items or rooms or anything like that, you can't miss a thing, whereas if you do a normal checklist going over it or something, you may miss something.’ (Participant #3)

However, some identified the danger of inconsistently interpreting BCA clauses. In many cases, different certifiers interpret BCA codes differently. Therefore, the assessment results produced by *Ignis* may not be acknowledged because certifiers may interpret code clauses in their own way. The participants stated

> ‘…the only problem I can see with it is the different interpretation of the BCA by the individual designer and certifier. I think that's the only way you'll get any inconsistencies at all.’ (Participant #3)
>
> ‘As a negative on something like this, it (*Ignis*) could then be used to belt someone over the head and say well look, this report says it does comply and you're telling me it doesn't. Because the interpretation are different (between *Ignis* and certifiers), then you get into an argument about this is right and you're wrong.’ (Participant #4)

These inconsistent interpretations may be caused by ambiguities in the BCA. The BCA is a complex document and is challenging to interpret. Many clauses in the BCA are cross-referenced to other clauses. Some contain open-ended conditions, and are thereby open to interpretation. One participant noted that he had inquired about an issue with the legislative authority (ABCB) and did not obtain a suitable answer. This reveals the following core issues in the NSW regulatory system: (1) the legislative authority provides clauses that certifiers do not fully understand and therefore cannot interpret accurately; (2) the legislative authority is not able to clearly explain and clarify their clauses.

> ‘when you start looking at the BCA, every section is so complex, and the interpretations are a bit scary, because it's all people's opinion as well - all how they interpret it. but sometimes the interpretations are different. It's kind of open to interpretation.’ (Participant #1)

> ‘how to interpret the BCA applying to the project. Sometimes it's not easy - the BCA isn't written to be that understandable in most circumstances.’ (Participant #6)

> ‘…I commonly send technical inquiries to the Building Codes Board and they don't understand it either.’ (Participant #5)

> ‘I've been to the biannual conference a couple of years ago…they gave us these questions and they turn out to be the hard questions people ring up and ask them. At the end of the day, what I realised was they really didn't know the answers and they were just trying to figure out what the answers… you're the Building Codes Board, you need to tell us the answers, and you know what I learned from this? I learned that my interpretation is as good as yours (ABCB), because you guys don't know any more what some of it means.’ (Participant #5)

These issues proved challenging in developing *Ignis*. Participants acknowledged the difficulties of interpreting the BCA and that *Ignis* could only go so far. Ambiguous BCA clauses resulted in obvious issues of interpretation.

> ‘So that's - the people are the problem, not your system. The people are going to be the problem. With some of these grey clauses in it, like Section C1, the stuff about whether this in-the-ground storey is, in fact, counted in the rise in stories, that's - you might get different certifiers who interpret that in a different way.’ (Participant #5)

> ‘it's only as good as the information and the interpretation of the certifier supplying the information, but that's not the problem of the system, it's the problem of the people using the system.’ (Participant #5)

However, this provides an opportunity for *Ignis* to align different interpretations of the BCA. As computer assessments are precise activities, results are unambiguous. Using *Ignis* can highlight issues in the BCA clauses that legislation authorities need to deal with. Moreover, this can avoid human errors in certifying activities. A participant said

> ‘the fact that it’s a regimented system means it’s starting to take out the whole human error potential. If it’s got the right information in it and it’s got the rigour in it, it is taking out that sort of potential for human error.’ (Participant #2)

In addition to identifying problems within the regulatory system, several issues specific to terms used in the BCA are discussed below. Several are outside of the scope of this study but indicate possible challenges for future developments of the system. These include atriums, building classes, and dwellings.

Atriums

The issue of identifying and determining the extent of atriums arose during the interviews. A certifier said

> ‘If we got a nightmare like an atrium… when I read the atrium stuff it seems to be cart before the horse stuff, because it tells you certain things in the part and then it sends you the specification, which seems to tell you completely different stuff. (Participant #5)

The BCA defines the atrium as

> ‘Atrium means a space within a building that connects 2 or more storeys, and –
>
> (a) is wholly or substantially enclosed at the top by a floor or roof (including a glazed roof structure); and
> (b) includes any adjacent part of the building not separated by an appropriate barrier to fire; but
> (c) does not include a stairwell, rampwell or the space within a shaft.’ (Australian Building Codes Board 2013: 20)

Although the BCA defines atriums in the above conditions, determining whether a space is an atrium or not is problematic. The definition contains ‘and’ and ‘but’ conditions that make it difficult to identify and determine atriums in a straightforward manner. The following is a participant's comments about these BCA clauses.

> 'you think you've got stuff in your head about the BCA but it's got so many twists and turns that you've constantly got to go back and check it…' (Participant #5)

In the model provided to participants, there are three open stairs connecting three storeys within an open space throughout the whole building (Figure 6.7). There was concern about fire spreading through the entire building. When stairs exist between three storeys, this creates a set of openings for a fire to spread through. This creates a potential compliance issue. Several participants determined this configuration as an atrium.

> 'It's not a closed stairwell. So you have to probably treat it as an atrium. Is that one there a void that goes straight through? (Participant #3)
>
> Yes, it is. (Researcher)
>
> That looks like that's definitely an atrium.' (Participant #3)

Another participant said

> 'If that's all open is it? So we've got holes through the floor on the upper level... probably, because of these openings here, if they were completely separated. Although they're open stairways, aren't they? (Participant #4)
>
> Yes, they are open stairways. (Researcher)
>
> So that would be an atrium.' (Participant #4)

Figure 6.7 Issues on atriums of the sample model

However, others disagreed and said

> ‘All right, well just off the top of my head, unless this building is sprinkler protected, you wouldn't be able to have those open stairs through the building… I've never considered open stairs throughout a building as an atrium, (so) I would just call them open stairs...’ (Participant #2)
>
> ‘No. I'd say it was a non-compliant stairwell, because it's not - I wouldn't imagine they're more than six metres. You've got to be able to stuff this six-metre thing down it to call it an atrium. There are some debates about that, but I would say they're just a non-compliant stair shaft, because it should be fire isolated. It's a 9b building, it's connected three floors, it would need to be fire isolated.’ (Participant #5)
>
> ‘For it to be an atrium I suppose you would need to have the levels open for a six metre radius in there. It just means that you've got interconnecting floors at three levels, requires sprinklers as a general rule.’ (Participant #6)

The responses above illustrate the difficulties of interpreting the BCA. They reflect and verify the fact that certifiers may make different and/or conflicting determinations when assessing a drawing. These variable assessments may result in additional time being spent and involve additional costs associated with revising designs. This impacts the quality of construction work and the selection of the FRL of materials.

Building classifications

Determining building classifications in accordance with the BCA provides a foundation for an assessment of compliance. The requirements of most code clauses are defined specific to a particular building classification. Section C of the BCA involves the required FRL of building elements to be established. According to Specification C1.1 Fire-resisting Construction, based on the same type of construction, class 7b and 8 have the highest FRL requirements while class 2, 3 and 4 have the lowest FRL requirements. Class 6 and Class 5, 7a and 9 are the two groups of classification at the second and the third places separately. Table 6.3 shows an instance of the FRL of external walls for Type A construction.

Table 6.3 Type A construction: FRL of external walls

Building element	**Class of building — FRL: (in minutes)** *Structural adequacy/Integrity/Insulation*			
	2, 3 or 4 part	**5, 7a or 9**	**6**	**7b or 8**
EXTERNAL WALL (including any column and other building element incorporated therein) or other external building element, where the distance from any *fire-source feature* to which it is exposed is—				
For *loadbearing* parts—				
less than 1.5 m	90/ 90/ 90	120/120/120	180/180/180	240/240/240
1.5 to less than 3 m	90/ 60/ 60	120/ 90/ 90	180/180/120	240/240/180
3 m or more	90/ 60/ 30	120/ 60/ 30	180/120/ 90	240/180/ 90
For non-*loadbearing* parts—				
less than 1.5 m	–/ 90/ 90	–/120/120	–/180/180	–/240/240
1.5 to less than 3 m	–/ 60/ 60	–/ 90/ 90	–/180/120	–/240/180
3 m or more	–/–/–	–/–/–	–/–/–	–/–/–

(Source from: Australian Building Codes Board 2013: 134)

The aforementioned sample model (a school, Class 9b) also contains multiple building classes including a cafeteria (class 6) and offices (Class 5). Most of the participating certifiers agreed that applying class 9b to the whole building was appropriate. However, clause A3.3 is a multiple classification of the BCA and states an additional condition when determining building classes. A3.3 defines the conditions of multiple classifications as

> 'Each part of a building must be classified separately, and
>
> (a) (i) where parts have different purposes — if not more than 10% of the floor area of a storey, being the minor use, is used for a purpose which is a different classification, the classification applying to the major use may apply to the whole storey; and…'(Australian Building Codes Board 2013: 42)

This involves determining whether additional building classifications exceed 10% of the floor area of a storey. In the sample model, the first and third storeys contained a cafeteria (Class

6) and offices having over 10% of floor area of the storey individually. Most participants stated there was no need to separate the cafeteria (Class 6) and office (Class 5) from the whole building (class 9b) and said

> ‘Generally speaking the offices and the cafeteria within a school building like this are ancillary to the main purpose group, so there’s no need determine Class 5 or 6 in this drawing. (Participant #2)
>
> ‘Well, it is the same classification. It's a different use so to speak. This is an assembly of people in the classroom. This is an assembly of people in the cafeteria. It's not actually a restaurant. So it's still a 9b. So I don't need to go and assess the 10 per cent ruling. (Participant #6)

However, the other two participants differed about whether the sample model contained additional building classifications. They said

> ‘So we go into the class of buildings, so basically it's all a 9b but that excludes any other part that has another class in it. So when you look at the cafeteria…(Participant #3)
>
> Would you determine the first storey having Class 6 and Class 9b? (Researcher)
>
> For that storey? If it is over 10% of the floor area in that storey, yeah I would. (Participant #3)
>
> Yes, it is over 10%. So does that mean you will make fire walls or doors to separate two different fire compartments? (Researcher)
>
> Depending on if it's got a kitchen or something makes fire in it. (Participant #3)
>
> So if it has a kitchen. (Researcher)
>
> If that's the case then you would have to have a fire door. But it's predominantly just a class 9B building.’ (Participant #3)

and

> ‘If this was commercially available to the public, I guess I would call it class six and we'd be fire separating it out of the building, but if it's just solely for the use of the school, I think I would just call it a 9B.’ (Participant #4)

These responses indicate differences in the ways the BCA was interpreted when participants were asked to determine multiple building classes within the sample model. All participants agreed the whole building was predominantly Class 9b. Reasons for determining a cafeteria as a separate class included whether it allowed access by the public or contained equipment that could give rise to fire. Determining that the building was Class 6 and not Class 9b has costs consequences (Class 6 needs a higher FRL than Class 9b). This reiterated the research problems (in section 1.2 at page 3) which identified that, in some conditions, certifiers rely on their past experience to make determinations that are different from others.

Additionally, determining the primary building class for the top storey of a building when considering the portion of floor area is problematic. In the context of the sample model, once the primary building class for the top storey has been determined, the Type of Construction can be decided in accordance with the number of storeys. The sample model was a three-storey building and the top storey contained a primary Class 9b (school) with a larger floor area than a Class 5 (office). The Type of Construction was then determined as Type A. However, once the portions of the floor area were exchanged, a Class 5 may be determined as the primary building class. In this case the Type of Construction was then downgraded to Type B and this has lower FRL requirements than for Type A. All participants agreed to use worst-case scenarios, but the participant with the most certifying experience was not confident when responding this issue. He said

> 'OK. Cut my tongue out. That's a good question. The Building Codes Board would love you. Well, you'd have to take the most onerous - notwithstanding the floor area, you'd have to take the most onerous classification on the basis of what it says there, so I would be applying the nine to the top storey. That's a very conservative approach. I'm not really known for my conservative approaches. Yes, that's how I would look at it.' (Participant #5)

Dwellings

An additional issue arose from a participant's past experience that was not related to the sample model. This issue related to residential building classifications, Class 1b and Class 3. Certifiers cannot determine exactly whether a complex residential building should be classified separately or individually because there is no definition of 'dwellings' in the BCA. The participant argued

> 'I was trying to determine a Class 1b to a Class 3 in regards to – if you read the definition of the classification, you can't have a Class 1b if it's above another dwelling… People will read that and say, well another dwelling is another one,

another Class 1b or another Class 1a. Or can't be any other classification, or can be any other class. Some people actually stack builders and tell them they're Class 3, because a dwelling isn't defined in the building code. So you can't – you look at the statement and there is no definition for the dwelling use. So it says you can't put something above, you can't put a dwelling above or you can't put this class above a dwelling. You think, righto, what's a dwelling? It's not defined. (Participant #6)

6.4.2.3 Report information

Assessment reports were produced in accordance with the results of the code-checking rules. The reports were produced in both visual and textual formats. This section explores whether or not certifiers felt these reports were understandable and reliable. The report formats referred to practical reports that addressed each clause. The reports were examined first and the participants responded as follows

> 'To actually get a report produced - at the moment, we have templates with all the clauses, and you go through each clause by clause by clause, '(Participant #1)

> 'The general in my report would be - would have the BCA clause, a definition of what it's about normally and then I'll have complies or doesn't comply. That's just a general way of doing it. I just have that to trigger what it's about. It doesn't always apply.' (Participant #6)

Although the participants normally reported clause by clause, one participant noted that this format may be cumbersome in practice. This participant observed that developers often do not read the full reports. They prefer to be informed directly what problems they need to fix. The participant said

> '… a full BCA report we do it very detailed, clause by clause, but they just want to know what they need to do. They don't really want to read the report. They probably don't even read the whole report. They'll just look at what are the problems, what doesn't comply, and what do I need to do to fix it?' (Participant #1)

This was supported by another participant who said

> 'I don't do it like that (clause by clause)... I do it basically section by section, because you end up with this massive document with all these clauses saying not applicable, so I generally do a report and say this is what this building needs, and anything that's not applicable I don't even talk about. I want to tell you what you need to know and what you need to do. I don't want to tell you about stuff that's not applicable to this

building. It cuts down the size of the report, gets to the important stuff. so I do not cover it clause by clause.' (Participant #5)

However, another participant was in favour of using the clause by clause format. The participant argued that checking building designs in accordance with the sequence of BCA code clauses may strengthen architects' awareness of the BCA. The participant said

> 'Well, it (the report) does help the understanding of each clause... I expect the architect to use it. They can gain knowledge (of the BCA) from this (report), in my experiences.' (Participant #6)

Regardless of the report format, participants agreed that the assessment results were reliable.

> 'the benefits to us are going to be obviously this reporting system to tell that what clause they comply... the documentation that it generates is reliable, it is going to be very helpful to us.' (Participant #4)

In addition, all participants appreciated the way the visual reports highlighted instances of non-compliance. This provided users with direct digital links to the target building elements. This was in contrast to manual processes where identifying issues could require reference to multiple hardcopy drawings. It was observed that the reports prepared by *Ignis* may change the ways certifiers and stakeholders communicate. Participants stated

> 'the beauty of that is that it takes you right to the spot where the issue is. If you're doing a manual check, you're looking at the walls and maybe you don't see that one at the end of the building.' (Participant #2)

> 'Visualising something in that format is a lot easier than reading a plan, a straight 2D plan. I can read plans, I'm quite good at it, but when you see it in 3D, you do realise that you actually, you're looking at something completely different sometimes.' (Participant #3)

> 'if there's non-compliances and it's easy for me to identify, visualise to then kind assist and consult back to the designer saying, well, make your compartment bigger or make it smaller or something like that, if they can't think of it themselves so to speak' (Participant #5)

> 'the architect wanted to show me the non-compliances and I'm sitting at my desk and he's downstairs and he sends it up and I'll be able to visualise it, obviously, that's

> what it's there for. I suppose, yeah, then try to figure out what the problem is and figure out how to make it work.' (Participant #6)

One certifier suggested strengthening the completeness of the report information by adding information relating to Australian Standards. Certifiers normally need to refer to the Australian Standards to assess building elements (for example, whether the FRL of a wall material meets the relevant Australian Standard). This is an area of further development for *Ignis* as knowledge of materials is outside the scope of this research. The participant stated

> 'It could probably go more into describing the type of materials that you're using, and probably even then again reference to Australian Standards. That's probably the only thing that would boost it up a bit more. We do rely a lot on Australian Standards when doing assessments, as well as the BCA as the main document, but we always refer to the Australian Standards.' (Participant #3)

6.4.2.4 System interfaces

Although *Ignis* was developed for architects, it may also be used by other disciplines such as certifiers. As these users may not be familiar with BIM-related technology, the *Ignis* interface needs to be simple and easy to use. All participants agreed that this was desirable. The participants agreed that the *Ignis* interface was simple and clear. They could easily operate the system through a few clicks. They said

> 'That is easy to use, yeah and it says BCA compliance and you go type of construct - it's very straight forward,' (Participant #1)

> 'I'd probably need to use it a bit more to really fully answer that question. But on the face of it, it doesn't look that challenging, it looks relatively simple.' (Participant #2)

> 'I reckon it would be easy to use. It wouldn't take long to learn it. When you're dealing with trying to generate reports and that, it wouldn't take long to learn it all. It's only a few clicks and you've got the list of what you need to do, so I think it'd be very easy to use.' (Participant #3)

> 'There are a lot of benefits for this one. Easy to use, you won't miss things, well that comes down to how much attention you pay in the first place and individual work.' (Participant #3)

> 'It seems to be fairly easy to follow through. You just click on different areas that you need to get access to and identify - the red obviously helps to identify what elements

> you want to focus in on. If you are curious about other parts of the building, you just click on those. That seems to be fairly intuitive.' (Participant #4)

> 'I see how this would be handy for the designer, I suppose, it will highlight components that are non-compliant for them to then address to make them compliant.' (Participant #6)

However, one participant indicated a downside to the *Ignis* interface. The operating window was floating and could not be fixed in Revit interfaces because the Revit API only supports floating windows. Therefore the reports produced by *Ignis* may occupy considerable screen space and overlap with other model visualizations. Moreover the reports are divided into many pages and users may spend considerable time looking for instances of non-compliance. The participant said

> 'The only problem to use this system, I think, you need to turn (report) pages to look for the red (non-compliant) and then you can get lost where you are looking to…yeah, the screen is not big, this model is hidden at the back…' (Participant #5)

6.4.3 Second revision of *Ignis*

The aforementioned participant identified an interface issue that may impede the use of *Ignis*. Revit does not provide open source code to allow interfaces to be embedded within it. This has meant that a floating window needed to be created to present reports. The previous version provided assessment reports in a multiple page format, requiring users to turn pages and scroll up and down to look for particular items. Moreover, the size of the operating window is fixed and may obscure 3D model presentations. These shortcomings informed the second revision of *Ignis*. A whole new interface was created (as illustrated in Figure 6.8). In this interface the window shape is adjustable and can be sized to fit in any spare screen space. The ways of highlighting design issues with red marks were retained in this version. When users click the identified objects, the BIM model object is highlighted in blue and is no longer obscured by the *Ignis* operating windows.

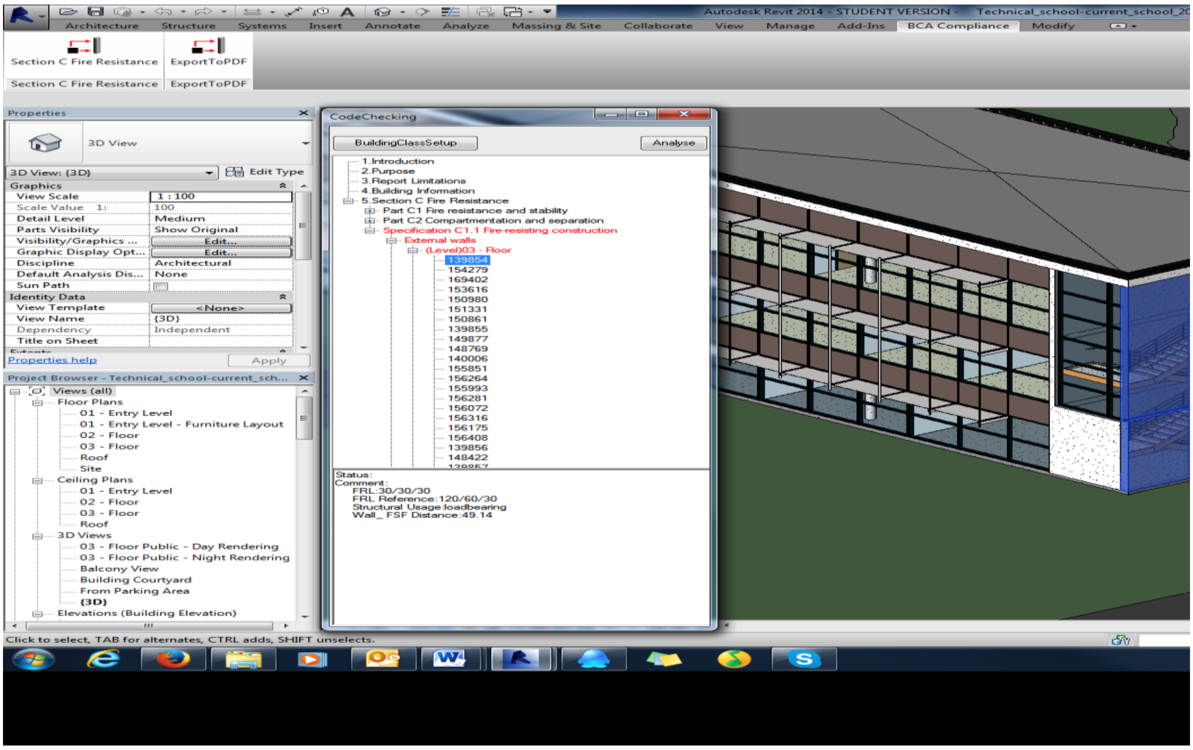


Figure 6.8 Revised interface of the 2nd version of *Ignis*

Figure 6.9 shows that this window is divided into two areas. The top one shows all code clauses presented in a tree structure. When specific clauses are selected, the bottom area of the screen displays information about their status and provides comments to users (for example, select Part C1 and then select Clause C1.1). The assessment results are then shown in the bottom column and instantly indicate whether the building element does or does not comply.

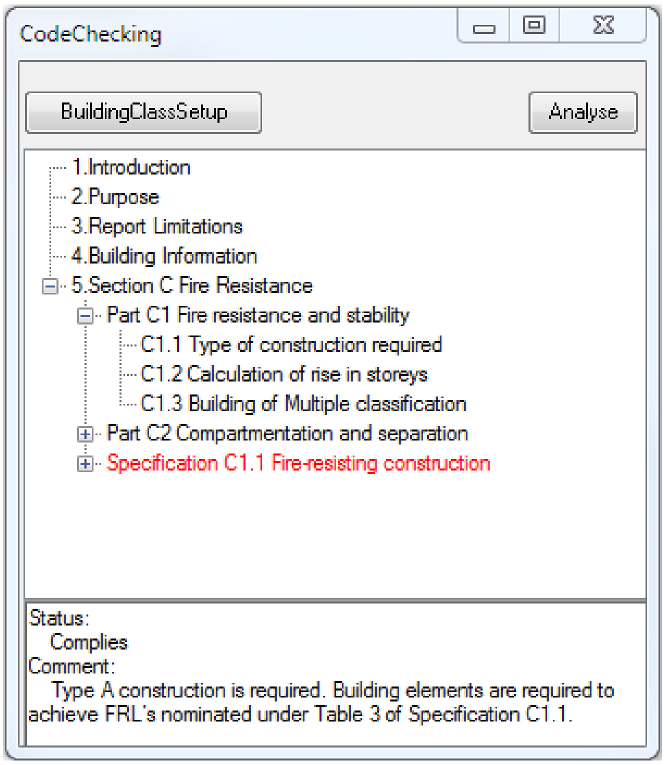


Figure 6.9 Layout of assessment information

6.4.4 Summary

In the first primary evaluation, six accredited certifiers were randomly selected from the ABCB website. These included a young certifier with four years certifying experience, whilst the others had more experience, ranging from twelve to forty years. Half of the participants had BIM knowledge and/or experience in using BIM. They were thus able to assess *Ignis* from multiple perspectives.

The preliminary evaluation process has been examined in section 6.3 (at page 116). It verified that the participants were able to provide suitable feedback against the evaluation criteria. The same evaluation process was then used in the first primary evaluation. Demonstrations of the system used the same sample model to examine the first revised *Ignis*. Participants were encouraged to operate *Ignis* to produce visualized and textual reports. They thus were able to to gain an understanding of how *Ignis* connected BIM and code compliance, how *Ignis* produced reports and how to interact with *Ignis* and BIM models. The evaluation results addressed four evaluation topics: system structure and code-checking rules, reports information and system interface.

Participants endorsed the *Ignis* structure for connecting BIM and code compliance. This was seen as an improvement on the inconsistent certification activities currently used in the building industry. *Ignis* was seen to provide effective functions that included examining BIM models against Section C building codes, producing reports in both visualized and textual formats and enabling users to interact with BIM models through the visualized reports. Using *Ignis* to assess BIM models, users obtained an instant assessment of compliance and thereby were able to revise models on the same platform. This reduces the time wasted manually checking work (by consultants and certifiers). In addition, incorporating *Ignis* into design processes may improve the consistency of assessment results thereby streamlining the certifying process.

By explaining how to interpret code clauses, participants were able to obtain an overall perception of how the code-checking rules were designed. The interview results provided evidence that the ways the *Ignis* rules examined the sample model were same as the procedures the participants used. However, the participants identified several problem issues including atriums, building classifications and dwellings. Identifying atriums in a building design was usually difficult. When assessing the sample model, most participants emphasized the significance of fire-spread as an issue, while the conclusions they made were different. It was also difficult to determine building classifications using the sample model. Although most participants agreed to apply class 9b to the whole building, several participants considered the cafeteria area on the first floor differently. Whether the cafeteria was open to the public and whether it contained equipment relating to fire influenced participants in determining the cafeteria as a separate Class 6 area of the building. These two issues are significant as they reveal that certifiers interpret BCA clauses in different ways (an observation which all participants agreed to). Such variable assessments may have implications for the schedule, cost, quality and safety of proposed buildings. The last issue related to dwellings and was outside of the scope of this research. The participant identified an obvious deficiency of the BCA - that it does not define the meanings or conditions of dwellings. It is thus inevitable that certifiers will determine such building classifications in different ways.

With *Ignis*, users only require a few mouse clicks to generate assessment reports. Afterwards, the visualized reports can be exported in PDF format. Participants were asked to examine the reports and assess their understandability and reliability. They acknowledged that the *Ignis* reports were understandable as they were similar to those which the participants produced in practice. The reports were designed clause by clause and were seen to be well tabulated. The text for each clause indicated whether it complied with the BCA and included comments describing reasons for the non-compliances as well as details of non-compliant objects. However, some participants suggested alternative formats. These participants preferred reports that summarized results section-by-section and excluded superfluous content, focusing on relevant design issues. A participant echoed this view, observing that many developers only wanted to know how to fix design issues instead of spending time reading reports. Based on some participants' experiences of working with project teams, the reports presented in a clause by clause format may enhance stakeholders' awareness of the BCA. In addition to the report formats, all participants agreed that a significant benefit of the visualized reports was that these enabled users to interact with BIM models. This meant that project teams and certifiers were able to gain a richer understanding of design issues.

During the demonstrations, all participants were provided with opportunities to interact with *Ignis*. This enabled the participants to evaluate the *Ignis* interface and comment on its simplicity and usability. They all acknowledged that the *Ignis*interface was simple. Moreover, it was easy to use *Ignis* to assess models for compliance and produce reports. Additionally, they all appreciated the visualized reports which enabled them to interact with BIM model elements. It was straightforward to locate problematic building elements as they were listed on the reports in red. However, the visualized reports were presented page by page. Participants needed to turn several pages to find each identified problem (marked in red). When small computer screens were used, the reports overlapped with the models and impeded usage. A second revision of *Ignis* was then undertaken to address the issues previously mentioned. A new interface with an adjustable window was created. This provided a window which was separated into two parts. Clauses, which were situated at the top, were displayed in a tree structure, thereby saving space. The bottom part of the window showed the status and comment information for each clause. Users were able to locate this new window in any spare screen space, thereby allowing more space to interact with BIM models.

The interviews with the six accredited certifiers highlighted several challenges. All agreed that the BCA was written in an ambiguous manner and that it contained gaps that were open to different interpretations by different certifiers, resulting in inconsistent assessment results. Solving this problem is outside the scope of this study. However, this study emphasizes the need for legislative authorities, BIM vendors and all building stakeholders to engage together to address this issue. This study has shown that *Ignis* can assess drawings for BCA compliance in consistent and efficient ways. Once stakeholders agree, BIM-enabled extensions like *Ignis* can be used to assist with BCA compliance checks and to generate consistent assessment results.

6.5 Second primary evaluation

Having redesigned the *Ignis* interface, a Design Science methodology was used to evaluate the second revision of *Ignis*. As the purpose of *Ignis* was to assist project stakeholders conducting BCA compliance activities during the design process, architects were engaged for the evaluation process. The participants included a group of architects working in an international company and two individual self-employed architects. The international company were invited for a group interview. Their staff work on projects developed using BIM technologies. The other two individuals were invited because they have considerable experiences working on BIM and collaborating with accredited certifiers. These enabled the researcher to engage them into evaluating *Ignis*.

For this group of participants, the techniques used in the evaluation process differed from those described in section 6.2 (at page 114). The first demonstration activity was undertaken in a boardroom. This included an explanation of the rules embedded within *Ignis* and model testing (using the sample school model). These activities were conducted through presentations that were projected on a whiteboard. These helped the group of participants to appreciate how *Ignis* connected BIM and code-checking concepts, how *Ignis* was used to obtain assessment results and what format the results were presented in.

Afterwards, a focus group interview was used to obtain participants' views. The architects were guided in their discussions through the following three topics: system structure, report information and system interface. In contrast to the expertise of certifiers, architects have limited knowledge of the BCA. Architects are therefore not able to provide expert opinions about whether the *Ignis* rules accurately reflect the requirements of the BCA. However, they are able to comment on the ways in which the system can be embedded into their design activities. The background of the participants is introduced in the next section. Their feedback about *Ignis* is discussed subsequently.

6.5.1 Participants

The number of participants in the second primary evaluation was seventeen. They included a group of fifteen architects from an international building design company and two individual self-employed architects (Table 6.4). All participants have been using BIM and/or have experiences in using BIM for design work. The architect group has been using Revit and ArchiCAD in their design processes for more than ten years while the other two individuals have experience of either ArchiCAD or Microstation. The group of architects comprised individuals in various organisational roles including a Principal, a National BIM manager, design team leaders and design team members. Most of their projects were commercial buildings including colleges, schools, hospitals and industrial buildings. The other two individuals were registered architects. One was a female who had more than five years experience in building design using ArchiCAD. Some of her work related to commercial buildings such as warehouses while most related to residential buildings. The other participant was an experienced male architect with more than thirty years experience. His exposure to BIM was less than ten years of using Microstation. He had strong experience of both residential and commercial buildings.

Table 6.4 Background of participants for the first primary evaluation

	Gender (Female/Male)	Position	BIM/design experiences (years)	BIM software	Design focus (commercial /residential)
Participant #Group	Male	Principle	30+	Revit & ArchiCAD	Both
	Male	BIM manager	15+		
	–	Team leaders	–		
	–	Team members	–		
Participant #7	Female	Self-employed	5+	ArchiCAD	Residential
Participant #8	Male	Self-employed	30+	Microstation	Both

6.5.2 Evaluation results

This evaluation focused on architects. The researcher used the second revised version *Ignis* for the evaluation work. The evaluation results were explored in the four topics as below.

6.5.2.1 System structures

The participants appreciated that a BIM-CCS application like *Ignis* provided a good way of assessing whether building designs complied with current building regulations. Throughout the design process, *Ignis* can assist stakeholders to test for BCA compliance in multiple assessment stages. The participants said

> ‘It's a tool that's part of a design process…it doesn't equate to the issue of pragmatism of an assessor. That's really what we need to have in any assessment process. That doesn't matter if it's BCA or DA or whatever else it might be.’ (Participant #Group)

> ‘It will greatly aid the architectural design process when designers move from Schematic to Construction documentation phase. It will act as a first step in highlighting the areas of the building which will require fire resistance, compartments and separation. During the documentation phase, the system will also aid in a cross-check against the BCA report.’ (Participant #Group)

Rather than recording which code clauses a building design has complied with, the participants highlighted that the significance of using *Ignis* was to identify what issues need to be dealt with to obtain compliance. *Ignis* can assist stakeholders in identifying information that is still required. For example, it is able to alert users to the FRL of building elements, the extent of fire compartments, as well as assist multiple disciplines dealing with cross-checking documents. *Ignis* was seen as a useful means of helping stakeholders make decisions when assessment results indicated instances of non-compliance. Therefore, *Ignis* may improve workflow in the design process. The participants said

> 'For example, it's a way of determining what our wall types and floor types need to be because we just use generic types. Run the test, this needs to be this, this needs to be that… so if you ran the test early in the process you'd get lots of red (marks) because nothing - and that would then at least start to inform how choose your wall types…' (Participant #Group)

> 'I think it can aid the design process, by eliminating design decisions which don't comply quickly.' (Participant #Group)

> 'Definitely the way of the future tapping in to the BIM data base technology used to design and document buildings. The more integration the better, particularly to improve work flow efficiency and cross checking.' (Participant #Group)

Participants added that incorporating *Ignis* into the design process would improve coordination of building designs, particularly when team members joined or left. *Ignis* can provide project information in any stage of the design process (e.g. in identifying the Type of Construction or building classifications). *Ignis* assists stakeholders who are new to a project to gain an overall understanding of the project. A participant emphasized

> 'It's really helpful for the project. At the moment, lots of people have been working on the same project, come on, gone off, come on. So if all that information was just - the class of the building was already in there, at least that gives you a point that you can go to rather than getting out the BCA and working out what class it is. It's already in the model to begin with which will save so much time with people that don't know that. The information is there because it's been set up properly to start with Consistency of interpretation.' (Participant #Group)

In addition, this participant identified *Ignis* as most suitable for large complex building designs. Stakeholders need to cope with large amounts of model information during the design process and would welcome assistance in identifying non-compliant building elements (such as FRL for multiple wall types with varied building classifications). The participant said

> ‘I think it's good for large complicated projects in the sense that the further we're going towards a lot of data input and materials and walls just helps us refine and not miss things, I suppose, as well.’ (Participant #Group)

Another participant observed that certifiers would see value in *Ignis* reports when these agreed with the certifier’s assessments. As such, he felt that *Ignis* would mainly benefit certifiers but leave stakeholders with responsibility to ensure that BIM models were accurate.

> So I guess my concern would be that it's very easy for the certifier, in that the design program is producing this document which gives them confidence to approve the job, but it's putting more responsibility on the designer, such as the quality of model... (Participant #7)

One participant argued that being responsible for the accuracy and quality of BIM data might increase stakeholders’ exposure to risks. He said

> ‘As per most calculated programmes, user input (error, omission or mis-understanding) is a risk which needs to be managed. Large amounts of user input upfront, whilst time saving in the long term does impact viability to some extent.’ (Participant #Group)

One participant identified the challenges of continually incorporating BCA revisions into *Ignis*. This is responded to the same issues that certifiers identified in section 6.4.2.1 (at page 124). The BCA is revised or a regular basis. If rules pertaining to the latest version of the BCA are not embedded within *Ignis*, the results it produces will be unreliable.

> ‘I think there are dangers because they change the codes and you would have to make sure that whoever's using the system has the latest. You have to insist that they have the latest because they could change the codes every year.’ (Participant #8)

6.5.2.2 Report information

When discussing the ways assessment results could be presented as reports, several participants firstly described the problems they had experienced. They highlighted a poor report as one that was not tabulated, not self-explanatory and only identified whether building elements ‘complied’ or ‘did not comply’ without comments or explanations. They observed that

‘The worst ones are the ones that don't have a tabulated form and you've got to interpret what they're saying. There's vagueness in that…or the ones that list the clauses and just have a tick box saying you need to comply.’ (Participant #Group)

Conversely, the participants indicated how assessment results could be well presented. The most useful reports were seen to be those that provided assessments in a systematic manner, clause by clause. The most important aspect was for non-compliances to be highlighted and for information to be provided on how to address them.

‘The majority that I'd be getting - and expecting to get - is the reports that go the same way systematically thought the code and gives you the clauses and those sorts of things. That generally would happen in the design phase. It's highlighting these are the areas that you need to think about designing, too, that you're going to get caught. Then in the design development, they're actually picking up where they're not complying.’ (Participant #Group)

‘The best reports are the ones where they stipulate the clause and then they have a column that says, complies, does not comply, or methods to comply. It's just spelt out really systematically and easy to read.’ (Participant #Group)

With respect to the *Ignis* reports, the participants provided positive feedback about both the textual and the visualized reports. They agreed that these reports were clearly understandable. Moreover, they appreciated the ways in which the visualized reports were connected to the BIM model elements through red hyperlinks. Furthermore, a participant noted that the reports that were formatted clause by clause were beneficial to stakeholders because they raised their awareness of the BCA.

‘I really appreciate the ability to find the referenced elements in the model. The report format is simple and clear, and is easily referenced to the specific parts of the BCA. The red text clearly highlights the non-conformances.’ (Participant #Group)

‘Do you like a report sorted out like this, clause by clause? (Researcher)

Personally, I do. I think including all of the clauses is helping to educate designers. Yeah. Whether it's compliant or not.’ (Participant #7)

6.5.2.3 System interface

During demonstrations, the two individual architects were asked to operate *Ignis* to gain a firsthand understanding of how it worked. However, only a few of the group of architects had an opportunity to gain hands-on experience of the system. The researcher provided a detailed demonstration of *Ignis* to the group, explaining what information it required and what results it provided, step by step. All their responses were positive. The participants emphasized and endorsed being able to interact with BIM elements when reports highlighted instances of non-compliance in red hyperlinks. They said

> ‘It is a very simple system, which is good, as you identified. You don't want to overcomplicate things.’ (Participant #7)

> ‘The interface on first appearance appears quite good. Integration with Revit tool bars is great. Links to the problem walls is an extremely helpful and successful feature.’ (Participant #Group)

> ‘through linking the user to areas which are highlighted as requiring review is an engaging feature which will ensure users can easily target items within the file rather than reading and then later having to find them independently.’ (Participant #Group)

6.5.3 Summary

The second primary evaluation was conducted with a group of fifteen architects and two individual architects to examine the second revised *Ignis* against three topics: system structure, reports information and system interface. Demonstrations using the sample school model were presented to participants. These enabled the participants to obtain an overall understanding of the ways *Ignis* operated. Interviews were then conducted with the group of architects and the two individual architects. Their feedback relative to the three topics is summarized below.

Firstly, the participants were appreciative of the *Ignis* structure, noting that it had great potential to assist stakeholders assess their designs from schematic to construction documentation phases. They emphasized that *Ignis* could be used to not only tell users what building clauses complied with the BCA but also to inform them what issues still needed to be dealt with. This was a great help when revising designs during the multiple stages of the design process. Moreover, participants saw potential for *Ignis* to be used to coordinate building design information particularly when team members changed because *Ignis* could help identify fundamental information (such as Type of Construction and building classifications). This enabled new members of design teams to gain a comprehensive understanding of building designs and thereby to engage in projects efficiently. Using *Ignis* was seen as a means of streamlining design and certification processes because it provides a consistent assessment, excluding the uncertainties that result from different interpretations of the BCA. One participant argued that, rather than providing benefits, using *Ignis* might result in additional stress and workload for stakeholders. This was because large volumes of data were needed in the early design stage. However, another participant stated if model data were managed in a timely manner, from a long-term perspective, time wasting would be reduced. This would affect the viability of building designs to certain extent.

In terms of report formats, participants acknowledged that the *Ignis* reports were clear and understandable. In addition, one participant thought that the reports, when presented in a clause-by-clause format, could help to educate stakeholders about the BCA. Based on the demonstrations, participants felt that the *Ignis* interface was simple and easy to use. Users can obtain assessment results after a few clicks. Significantly, participants highlighted the way users interacted with BIM models through the visualized reports and noted that this was a useful feature of *Ignis*. It enabled users to locate problematic building elements efficiently rather than having to review numerous 2D drawings.

Overall, *Ignis* has been examined and verified against the three topics of the system structure, reports information and system interfaces. The evaluation criteria for each topic have been discussed above. Although most participants appreciated the benefits of *Ignis* when incorporated in the design process, several issues, including the accuracy of BIM data, additional responsibilities of stakeholders, and inconsistent interpretations of the BCA remained as concerns. A complete and fully-functional *Ignis* that provides consistent assessment results for BIM models is feasible if BCA clauses are reworded in an explicit manner.

6.6 Evaluation framework

The participants' feedback, based on iterative evaluations, has been discussed relative to the four topics (system structure, code-checking rules, reports information and system interface) in the previous sections. Most of their feedback about the development of *Ignis* was positive. In Design Science research, evaluations need further exploration to demonstrate the ways *Ignis* works to achieve its purpose. Section 4.6 (at page 80) has identified various evaluation elements for each topic (e.g. the functionality of the system structure and the simplicity of the system interface). The participants' feedback was then explored against these evaluation criteria. These are summarized below (Table 6.5).

Table 6.5 Evaluation framework for *Ignis*

Evaluation Criteria	Results
System Structure	
Functionality	Both accredited certifiers and architects agreed that *Ignis* successfully reads BIM parameters and executes code-checking rules by examining the BIM parameters. The results of checking are presented in both visualized and textual formats.
Better solutions to the problem	Both accredited certifiers and architects agreed that using *Ignis* was a better solution to the research problems. Stakeholders have little knowledge of the BCA and little ability to assess their building designs for compliance during the design process. Furthermore code compliance consultants may not be involved in the entire design process. *Ignis* provides a solution to assist code compliance works for building designs during the design process.
Impacts on environment and users	Accredited certifiers agreed that using *Ignis* to assess building designs can change the ways in which industry operates. Architects agreed that incorporating *Ignis* into the design process to assess BIM models can alter the whole process from the schematic phase to the construction documentation phase.
Efficiency	Both accredited certifiers and architects agreed that *Ignis* provides assessment results in an efficient way. Users are able to instantly revise BIM models on the same application platform.
Efficacy	Both accredited certifiers and architects agreed that *Ignis* performs effective code-checking activities. Therefore stakeholders can use the assessment results to decide on ways of revising building designs during multiple stages of the design process.
Code-checking Rules	
Consistency	Accredited certifiers agreed that the code-checking rules embedded in *Ignis* examine BIM models in a consistent manner. However, they also identified several issues that may result in variable results. These are outside of the scope of this study.
Effectiveness	Accredited certifiers acknowledged that the way *Ignis* interprets BCA clauses and creates rules is effective. This process replicates their manual certification procedures.
Report Information	
Understandability	Both accredited certifiers and architects agreed that the reports that are generated clause by clause are easy to understand.
Reliability	Accredited certifiers acknowledged that the *Ignis* reports that inform users whether or not their drawings 'comply' are helpful. Furthermore, they provide comments that describe issues and possible solutions. The reliability of the reports was verified by certifiers using the sample model.
Side effects	Both accredited certifiers and architects mentioned that the *Ignis* reports may be used to inform and educate stakeholders about the BCA.
System Interface	
Simplicity	Both accredited certifiers and architects agreed that using *Ignis* was simple.
Usability	Both accredited certifiers and architects agreed that they can easily obtain assessment results after a few mouse clicks. In particular, they appreciated a feature of *Ignis* that enabled users to interact with BIM model elements when reports indicated instances of non-compliances in red hyperlinks.

6.7 Evaluation of the research process

Ignis has been examined and evaluated against the evaluation framework described in previous sections. Within the context of the Design Science research, and in addition to assessing the artefact (*Ignis*) against the evaluation framework, the methodology and methods used in this study have met the Design Science principles proposed by Henver et al (2010). These principles were explained in section 4.4.1 (at page 71), and have been applied to the research process for this study. Each principle is described below.

Principle #1 Viable artefact

This study created an artefact, *Ignis*, on the Autodesk® Revit® platform. *Ignis* can read and examine BIM models against code-checking rules. The code checking rules were devised to accommodate the text-based rules set out in the BCA. The assessment results are presented in both textual and visualized reports. These reports inform users whether building designs ‘comply’ or ‘do not comply’ with each clause of the BCA.

Principle #2 Problem relevance

The study has identified the absence of tools that assist stakeholders to assess how their designs comply with the requirements of the BCA during the design process. Therefore the researcher developed an artefact, *Ignis*, to address this issue. However, the BCA is a large document, containing numerous clauses. This study could not address them all. *Ignis* was developed to assist stakeholders to assess commercial building designs against the several codes in Section C of the BCA only.

Principle #3 Design Evaluation

Within the context of Design Science research, many studies have identified multiple evaluation criteria such as functionality, efficacy and usability. Kanjanabootra (2013) collected evaluation criteria from many studies and identified twenty-two items as criteria. However, evaluation criteria vary in accordance with the purpose of the artefacts. This study has adopted twelve evaluation items and these were categorized into four topics for *Ignis*. They were ‘system structure’, ‘code-checking rules’, ‘report information’ and ‘system interface’. *Ignis* was examined through three sequential evaluation activities against these four topics.

Principle #4 Research contributions

This research has contributed to the body of knowledge related to the specification and development of a BIM-CCS, specific to the Australia building industry, to assist with the assessment of design compliance during the design process. This includes how to interpret building code clauses so that these can be embedded within design rules, how read BIM parameters to inform the code-checking rules, and how to produce reports in accordance with the assessment results. *Ignis* is seen as a significant outcome of this study.

Principle #5 Research Rigour

Robust Design Science research relies on the application of rigourous research methods (Hevner, A. and Chatterjee 2010). This study firstly adopted a combination of DL and RASE methods to interpret building code clauses. *Ignis* was firstly examined by a range of BIM models. Afterwards, three phase evaluations were conducted using demonstration and interviews techniques to examine *Ignis* against the evaluation criteria.

Principle #6 Design as a search process

A good research design requires iterative evaluation processes (Arnott and Pervan 2012). This study adopted three phases of evaluation including preliminary, first primary and second primary evaluations. Two different professional groups were invited for the evaluations. One and six accredited certifiers participated in the preliminary and first primary evaluations separately. A group of fifteen architects and two self-employed architects participated in the second primary evaluation. This enabled *Ignis* to be refined as an optimal solution for the identified research problems.

Principle #7 Communication of research

Artefacts built using a Design Science methodology must be understandable and usable by technically-orientated and management-oriented users (Hevner, A. and Chatterjee 2010). The researcher understood that implementing *Ignis* involved architects and certifiers. *Ignis* needed to be verified by certifiers to assure the integrity of the rule designs and refined to clearly inform architects whether building designs complied or not. It was identified that using *Ignis* may potentially streamline the design and certification processes.

6.8 Summary

This chapter has described the evaluation process for *Ignis*. This included three phases: preliminary, first and second primary evaluations. The techniques used in the evaluation process were demonstrations and interviews. *Ignis* was initially demonstrated to participants using graphic-supported explanations of rule designs and a sample BIM model (provided by Autodesk® Revit®). Assessment results were then presented in both visualized and textual formats. Participants were invited to operate *Ignis* to check the sample BIM model for compliance with the BCA codes for fire-resistance, produce assessment reports and interact with BIM models by clicking red hyperlinks (indicating instances of non-compliance) on visualized reports. Twelve evaluation items (indicated in Table 6.1 at page 116) were used to examine *Ignis* in four topics: system structure, code-checking rules, report information and system interface. The contributions of the three evaluation phases are summarised for each topic below.

Each iteration of evaluation contributed and informed the next round of revision of the system. These iterative *processes* (i.e. the preliminary, first and second interviews) have been explored against the four evaluation topics. These underpin the potential and capacities of *Ignis* in assessing BIM models for compliance with the fire resistance codes.

 # System structure

- Participants agreed that *Ignis* connected the concepts of BIM and code-checking to provide a solution that addressed the research problems of this study (Section 1.2 at page 3).
- *Ignis* provides effective facilities for examining BIM models against the Section C codes, producing textual and visualized reports, and interacting with users, BIM models and reports.
- Users can efficiently revise models when informed of instances of non-compliances in reports.
- *Ignis* provides consistent assessments and can potentially streamline design and certifying processes.
- Incorporating *Ignis* in design processes can inform users what issues they need to deal with in addition to what clauses are complied with.

 # Code-checking rules

- Accredited certifiers acknowledged that the ways *Ignis* interprets Section C codes for rule designs are affective.
- BCA clauses are open to interpretation and may result in inconsistent assessment results.
- Several issues within the BCA were identified: atriums, building classifications and dwellings

 # Report information

- It was easy to obtain assessment reports.
- Results are presented clause by clause on the reports and are clear and understandable.

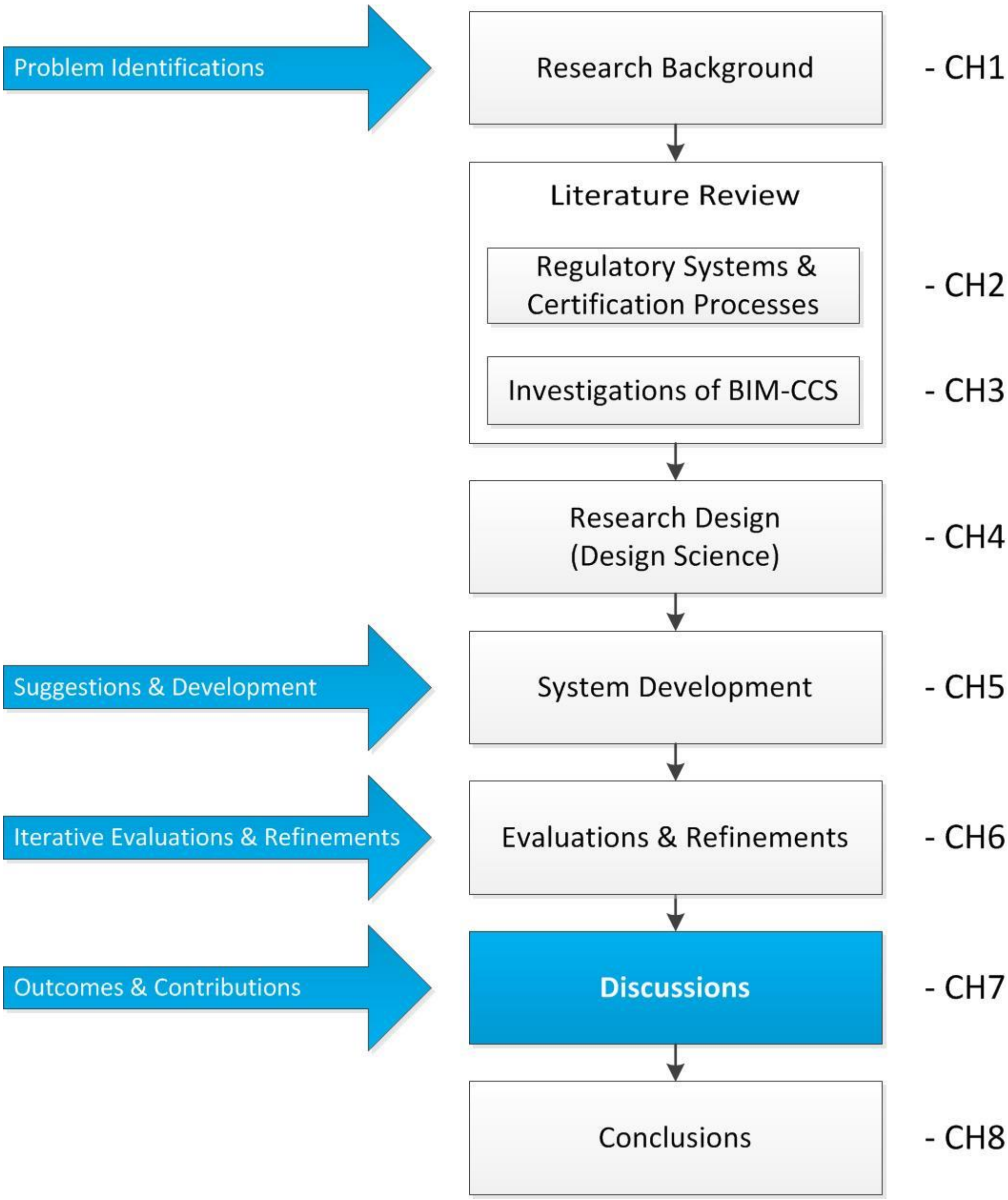
- Accredited certifiers endorsed the *Ignis* reports as reliable.
- All participants appreciated a feature of *Ignis* that enabled reports to locate building elements for users.
- Reports are presented clause by clause and can potentially educate stakeholders about the BCA.

 # System interface

- The interface was simple and easy to use.
- Instant assessment results only require a few clicks.

These outcomes and issues were generated from the evaluation processes. They are discussed further in the next chapter.

7 DISCUSSION



7.1 Introduction

The evaluation process and results for *Ignis* have been described in the previous chapter (Chapter 6 at page 112). The participants assessed *Ignis* against four topics: system structures, code-checking rules, report information and system interfaces. In addition to validating *Ignis* against the selected evaluation criteria, the potential capacities and challenges of implementing *Ignis* were identified.

This chapter firstly discusses the capacities of *Ignis*, emphasizing how it assists project stakeholders to incorporate code-checking activities into their design processes. It describes how the performance and productivity of building designs can be enhanced. Moreover, it describes how *Ignis* allows project stakeholders to strengthen their knowledge of the BCA and their abilities to solve compliance issues through code-checking activities.

This is followed by discussions of the challenges faced in developing the BIM-CCS. These relate to the inherent difficulties of interpreting building regulations and of insufficient information to inform code-checking rules. For example, several clauses of the BCA were open to different interpretations and various parameters of BIM models could not completely support the code-checking activities. In addition, creating BIM models with sufficient information presented an external challenge to the BIM-CCS. BIM models need to be created according to defined procedures to inform code-checking activities and these are described in the next section.

Few studies have proposed methodologies for developing BIM-CCSs. This study has demonstrated the use of a Design Science methodology to support such a development. *Ignis* is a purpose-built artefact created to address the identified research gaps using Design Science. The knowledge and contributions produced from the entire development process are discussed in the last section.

7.2 *Ignis* Capacities

This study has developed a code-checking system, *Ignis*, on the Revit 2014 platform. Its intention is to check commercial buildings against the Section C Fire Resistance of the BCA. *Ignis* can read parameters directly from BIM models and use these parameters for code-checking activities. Stakeholders can then incorporate *Ignis* into their design processes and use it to check their designs in any stage. The opportunities for incorporating *Ignis* into design processes were identified by those interviewed. These are discussed below.

7.2.1 Efficiency

The ways *Ignis* assessed BIM models and produced assessment results were noted as efficient. Accredited certifiers currently need to review and assess large numbers of design drawings against building regulations. The accredited certifiers interviewed indicated that assessing a medium level building design took one to two working days for reviews and some additional days to prepare reports documnenting their findings. This means that project stakeholders may wait about a week to obtain their assessment reports. Should the building design not comply, certifiers do not explicitly identify problematic objects in their reports. This results in project stakeholders having to spend additional time solving design issues.

The interviewees acknowledged that *Ignis* assisted greatly by exploiting computer technologies in assessing and reporting activities. *Ignis* can read BIM model data and produce code checking assessment results in both textual and visualized reports. The entire assessment process only requires a few clicks and takes seconds to execute. Should the assessment reports identify design issues, the visualized reports can be used to locate problematic objects. This confirms that *Ignis* provides meaningful assessment results and alerts users to problematic issues in an efficient manner.

7.2.2 Consistency

The accredited certifiers agreed that *Ignis* performed code-checking activities consistently regardless of the inherent challenges of interpreting BCA clauses. It was observed that, for a particular building design, different certifiers provided different assessment results. In addition to human error, the interviewees acknowledged that inconsistent assessments resulted from some code clauses being ambiguous and open to different interpretations. *Ignis* was able to bypass these ambiguities and was able to provide consistent assessment results because the rules embedded in the system were designed in a systematic manner.

The BCA clauses were interpreted by semantic analysis methods to inform the rule designs. *Ignis* is able to directly read the model parameters and match these to code-checking rules. Each rule was designed by a series of decision-making processes. These processes may not be altered by users and/or third parties and therefore are able to assess building designs in a consolidated manner. This means that no matter who uses the system, the assessment results produced by *Ignis* are the same. This prevents human errors in assessing building designs.

7.2.3 Streamline design and certification processes

The interviewees acknowledged that *Ignis* was able to streamline design and certification processes for stakeholders. *Ignis* enables building designs to be checked for compliance against various conditions during the design process. Once instances of non-compliance have been identified in building designs, project stakeholders can propose solutions. Stakeholders can remedy their design solutions and re-assess them until the *Ignis* reports indicate that all code clauses have been complied with. This effectively reduces the risk of non-compliances during later certification stages.

Accredited certifiers can use the *Ignis* assessment reports as references to assist in determining whether building designs comply. The *Ignis*reports not only communicate whether building designs comply but provide fundamental model information (e.g. floor areas and volume) for manual assessment. This assists accredited certifiers by reducing the time they spend exploring and calculating drawing information, thereby enabling them to verify the *Ignis* reports in an efficient manner.

BIM-related technologies have been seen as revolutionary, with the potential to alter and improve traditional design processes (American Institute of Architects (AIA) 2007, RIBA 2012). However, few applications emphasize the relationships between design and certification processes. *Ignis* is a means of connecting design and certification processes because *Ignis* can produce consistent assessments as reference artefacts for all stakeholders. This shows that *Ignis* can be used to engage project stakeholders and certifying authorities to communicate and collaborate using a shareable platform. This reiterates the observation that the BIM-integrated design process (described in section 3.3.3, page 32) engages multiple disciplines in collaborating in the early design stage and thereby effectively alters traditional design processes (Ireland 2009, Sacks, R. and Barak 2008).

The early participation of certifying authorities and/or consultants enables the time spent on the Agency Permit and Bidding stage to be shortened (American Institute of Architects (AIA) 2007, Ralph 2001). This means that the coordination of a project can reach a more mature level during the design process, thereby reducing the risk of construction variations occurring and shortening the construction period (Deutsch 2011). Engaging certifying-related parties early has been shown to improve the performance and productivities of building designs (American Institute of Architects (AIA) 2007).

7.2.4 *Ignis* reports inform decision making

The participant architects recognized the capacity of the *Ignis* reports to support stakeholders in exploring and determining solutions. These reports (including textual and visualized reports) are formatted in accordance with practical certification reports, which present assessment results clause by clause. In the *Ignis* reports, each clause has ‘status’ and ‘comments’ columns to communicate whether buildings ‘comply or do not comply’ and ‘reasons for the status’. Taking code ‘C2.7 separation by fire walls’ as an example, a building design may not comply with the code requirements because the firewalls have an underrated FRL. *Ignis* will report that the walls do ‘not comply’ in the status column and identify that they have not reached the required FRL in the comment column. Moreover, the comment column also identifies object information relating to the firewalls including object numbers, locations, current FRL and suggested FRL. In this case, stakeholders can decide to either use firewalls of a higher FRL or modify the fire separations. In addition, stakeholders can explore other possible solutions through iterative examinations using *Ignis* untill adequate solutions are found. The architecture participants were most appreciative of this facility because the reports they normally receive from accredited certifiers do not provide advice about remedial alternatives. Meanwhile, as the participant certifiers emphasized, in practice, accredited certifiers are not permitted to suggest solutions where designs are found to be non-compliant. This is because such advice would present a conflict of interest (as certifiers are not responsible for design decisions). This lack of prescriptive advice makes it difficult for project stakeholders to take appropriate actions to solve issues. It further highlights that integrating *Ignis* into the design process can assist stakeholders in exploring, examining and selecting appropriate solutions.

7.2.5 Improve awareness of the BCA

Using *Ignis* to assess building designs may potentially enable project stakeholders to gain BCA-related knowledge through the aforementioned iterative modification and assessment activities. The participant architects saw this as a positive contribution, observing that they usually do not have a detailed awareness of building regulations. This may be because architects view building regulations as a burden that hinders their creativity and innovation (Fischer, J. and Guy 2009, Hunt and Raman 2000). However, understanding building regulations can be a powerful tool to create, construct and manage designs (Alberti and Rykwert 1991, Ralph 2001). Bentley (2004: 27) agrees with this viewpoint, stating that building regulations enable architects to 'get to grips with the otherwise implausibly complex flux of the world'.

Advisors and/or consultants on certification usually participate at the very end of the design process. This results in architects having to take on most of the responsibilities of securing regulative approvals for building designs. Should building designs not conform to regulative requirements at this late stage, schedule delays and budget overruns may ensue. Thus engaging regulative advisors or regulative assessment technologies during the early design stages can avoid non-compliant designs reaching an advanced stage. *Ignis* is a vehicle that assists architects to steer clear of these circumstances. It facilitates practitioners to develop their knowledge of building regulations through iterative assessments.

Although this learning process accumulates as the result of practical experiences, integrating *Ignis* into design process enables architects to examine new strategies to solve design issues through iterative trial and error activities (Young, H. P. 2009). The consistent and efficient assessment reports produced using *Ignis* supports this statement. Moreover, the trial and error process which *Ignis* facilitates has been shown to enable creative and innovative outcomes to be produced (Sosna et al. 2010).

7.3 Challenges in developing *Ignis*

The development and evaluation of *Ignis* unearthed several challenges. Some were inherent in the BCA clauses and some resulted from the BIM technologies used. The interviewees recognised these challenges. In addition, the ways of creating BIM models affected the success of the code-checking activities. This involved users' level of knowledge and abilities to create BIM models. These challenges are discussed sequentially in the following sections.

7.3.1 BCA is ambiguous and open to interpretation

The BCA clauses are, in some cases, written in an ambiguous manner. This meant that it was not possible to fully interpreting BCA clauses for BIM-CCS rule designs. Building-related professionals agree that the BCA is extremely complex, prescribing requirements from various perspectives for structure, fire resistance, access and egress, services and equipment, health and amenity, ancillary, special use buildings, maintenance and energy efficiency. A significant part of the BCA clauses also needs to be compatible with Australian and/or New Zealand Standards. The certifiers interviewed all agreed that the BCA is not easy to use. Furthermore, most building-related professionals find it frustrating and complex (Fischer, J. and Guy 2009). The certifiers highlighted that many BCA clauses contain complex cross-references and open-ended conditions, with the consequence that different certifiers may interpret clauses in different ways, resulting in inconsistent results.

Additionally, several significant items written in clauses are not defined or are poorly defined. Those for *Atriums*, *Cafeterias* and *Dwellings* have been identified in this category. Although Atriums are defined in the BCA, the ways to interpret and determine Atriums were found to be inconsistent. This was verified by the participant accredited certifiers. They considered the Atriums of the sample model in various different ways.

Furthermore, the *Cafeteria* has been inconsistently determined as either Class 6 or Class 9b. This inconsistency was not resolved until it was categorized as *Class 6* in the revised version of the BCA for 2008. Of significance when determining *Cafeteria* as Class 9b, is the perspective of fire resistance. The FRL for building elements can be downgraded (from Class 9b to Class 6), thereby reducing costs. In addition, the ways of determining whether the *Cafeteria* in the sample model needed to be a separate fire compartment were identified differently by different participants. Some saw the cafeteria as a part of a Class 9b building whilst some determined it as a separate fire compartment if the cafeteria was accessible to the public or contained fire-related equipment.

An additional ambiguity identified by the participants was that of a 'dwelling'. This term has never been defined in the BCA. A 'dwelling' may be determined as either *Class 1b* or *Class 3*. This can result in completely different requirements from all perspectives.

These examples highlight the inconsistent manner in which accredited certifiers interpret the BCA. Certifying authorities interpret and determine results relying on their personal experiences. The inconsistency of their determinations presented challenges for the development of *Ignis*. Although this study adopted a combined semantic analysis method (using DL and RASE methods) to identify significant features for rule designs, the aforementioned examples made it difficult for explicit interpretations of rules to be incorporated into *Ignis*. As many participants noted, the most significant problem of developing and implementing a BIM-CCS is the inconsistent manner in which clauses can be interpreted.

7.3.2 BIM is not fully supportive of code-checking

BIM technology has been acknowledged as an effective vehicle that can be extended for multiple purposes such as clash detections and schedule arrangements. However, within the development of *Ignis*, the researcher encountered several BIM-related challenges. These are discussed from two perspectives.

Firstly, BIM parameter template settings were varied and not designed to accommodate the requirements of BCA clauses. BIM parameter settings were obviously designed from the perspective of target users – project teams. However, stakeholders usually lack awareness of building regulations (Fischer, J. and Guy 2009, Hunt and Raman 2000). The building regulations were therefore not prime concerns when BIM parameter settings were devised. These prohibited *Ignis* from obtaining the required BIM parameters to commence code-checking activities. Additional calculations and/or manual work (e.g. identifying mezzanines and building classifications) were needed and thereby put a heavy burden on stakeholders.

Secondly, the interoperability of BIM models between different BIM software packages was a concern. Although IFC schemas have been developed to mitigate this issue, several challenges still need to be overcome. Relevant research has identified that transferring BIM models between Revit and ArchiCAD using IFC 2x3 schema may possibly result in geometrical disconnections and a loss of BIM parameters (buildingSMART 2009c, Lê et al. 2006). These issues may obviously impede the development of *Ignis*-like systems.

7.3.3 BIM policies for project stakeholders

When a design team begins a building design, a BIM policy (at team and/or organizational levels) is needed. This is represented as guidelines and processes that enable BIM models to be created in a coordinated manner. All stakeholders should follow the same procedures to create digital models, set parameters and document model drawings. In addition to coordinating models between stakeholders, the BIM policy can strengthen their abilities in BIM modelling.

BIM policies are important in BIM-CCS research because they instruct project stakeholders how to create BIM models and what BIM parameters are necessary for code-checking activities. For example, with mezzanines, some architects may not set mezzanines as independent levels. Instead, they may create floors offset from a lower storey. This results in mezzanines and their lower storeys being built within one level. This is problematic for *Ignis* because the system cannot identify mezzanine levels defined in this way, leading to ineffective assessment results. This emphasizes the importance of BIM policies in the BIM-CCS research domain. Once BIM policies are informed about the requirements of BIM-CCS, BIM policies may be revised to acknowledge their requirements at regional or country levels.

7.4 Design Science methodology supports BIM-CCS development

Design Science methodology has underpinned the entire development process of *Ignis*. Design Science methodology research was used to inform the researcher how to find answers to the identified research problems in a systematic manner (Peffers et al. 2007). Design Science methodology set frameworks which guided the researcher to explore research gaps, propose suggestions, develop artefacts as solutions, evaluate artefacts and produce knowledge as contributions (Arnott and Pervan 2012, March and Smith, G. F. 1995, Purao 2002). Methods and techniques were investigated and the most appropriate ones were then chosen for each stage. This enabled the purpose-built artefact, *Ignis*, to be created and evaluated in a holistic and systematic manner.

Nine BIM-CCSs were investigated in section 3.6 (at page 44) but few explored the methodology used to develop the BIM-CCS. These studies emphasized computational techniques of developing BIM-CCSs. In particular, they focused on how to create code-checking rules using developed rule engines (i.e. Solibri, EDM, FORNAX and Smartcodes discussed in section 3.5 at page 42) and how to extract BIM model parameters to inform the commencement of code-checking rules. After the completion of BIM-CCSs, most of these studies dealt with evaluation of how these systems performed using sample BIM models. These sample models were either provided from external parties or created for testing purposes only. For example, a purpose-built BIM model was used to examine the efficacy of InSightBIM-Evacuation against code evacuation rules (Choi, Jungsik et al. 2013).

However, these evaluations involved few building compliance-related experts and/or users (such as certifying authorities, architects or the like). Within Design Science methodology research, user experience and feedback are significant and enable purpose-built artefacts to be refined to meet users' needs (Adikari et al. 2011, Chin et al. 1988, Davis 1993, Wilson et al. 1997). This highlights that users and/or related experts play significant roles that may significantly impact the development of artefacts. *Ignis* was an artefact created specific to project stakeholders' needs and used to identify and solve instances of non-compliant design during the design process. Therefore it was necessary to engage users and related experts in the entire development process, and particularly in the evaluation process (Adikari et al. 2011).

In this study, *Ignis* is seen as a purpose-based artefact created using Design Science methodology. Design Science methodology research emphasizes the iterative process of development, evaluation, and identification of further suggestions (Vaishnavi and Kuechler 2015: 11–12). Evaluation work was conducted with accredited certifiers and architects in three phases including preliminary, first primary and second primary evaluations. These confirm that *Ignis* is credible and meets users' needs, compared to the other BIM-CCSs surveyed. The development and evaluation processes are discussed in the following sections.

7.4.1 Development process

The ways to create *Ignis* can be categorized into two topics: clause interpretations and rule designs. Clause interpretations represent the ways of interpreting the BCA clauses in an explicit manner. Semantic analysis methods were adopted to deal with the interpretation work. This enabled the researcher to identify key items such as objects, requirements and relationships (between objects and/or clauses). This enabled the researcher to deal with rule design work.

In terms of rule designs, the researcher needed to design rules in accordance with the results of clause interpretations. Several clauses were analysed and disassembled in readable items that could be directly identified from BIM parameters. The 'FRL' of 'external walls' is an example where BIM can directly provide information for these two items. However, some clauses may require items that BIM parameters cannot provide. 'Average internal height' and 'mezzanines' are examples that need further calculations and/or additional work.

The methods of semantically analysing the BCA clauses, and the ways of producing rule designs and solving challenges are discussed below.

 # Clause interpretations

Most of the BIM-CCS rules in the systems reviewed earlier (in section 3.6, page 44) checked the spatial dimensions or volumes of a building. For example, DesignCheck checked the accessibility for disabled people (Ding et al. 2006). However, not every BCA clause is defined in a simple and straightforward manner. Some contain abstract objects, descriptive requirements and conceptual relationships. This means that users need to define additional parameters or perform additional calculations. For example, to measure the distance from exits to fire source features, Solibri requires users to manually attach the parameter ‘exits’ to external doors. This additional work is required to successfully execute code-checking activities. This obviously confuses users if they are not aware that this needs to occur (Adamczyk and Bailey 2004, Iqbal et al. 2004).

This study used a combined semantic analysis method (comprising DL and RASE methods) to interpret Section C Fire Resistance codes (described in section 4.5.1 at page 74). Both methods were developed specific to building regulations within the BIM-CCS research domain. Notwithstanding this, their functions were not the same. The DL method, in addition to identifying the key items of code clauses, emphasized the hierarchical relationships of building codes. This facilitated programming work to classify rules in dominant or subordinate positions. The RASE method strengthened the disassembly of significant items of code clauses in four categories: Requirement, Applicability, Selection and Exception (Hjelseth, Eilif and Nisbet, Nick 2011). This approach has been applied and verified in several studies (Hjelseth, Eilif and Nisbet, Nick 2011, Hjelseth, E. and Nisbet, N. 2010, Nisbet, Nick and Dinesen 2010), enabling the rules to be designed in a reliable manner. This study combined these two semantic analysis methods and adopted their advantages to design and arrange the *Ignis* rules. Through this combined method, code clauses can be interpreted in an understandable manner and this thereby assists with rule design. In the meanwhile, disassembled clause items that were challengeable or not achievable could be identified for further discussions.

 # Rule designs

Code-checking rules were designed in accordance with the results of clause interpretations. The researcher used process models to design and present how the code-checking rules operate (Ambler 2005, Fowler 2004). Process model is an object-oriented engineering method used to specify, visualize, construct and document the artefacts of software systems (Booch 1994). Process model graphics have been demonstrated as an effective means of communicating with programmers (Dobing and Parsons 2006, Odell et al. 2000). Several rules designed by process models have been discussed in the section 5.3 (at page 87) and all the rules designed are presented in Appendix 2.

Through the rule design process, several challenges were identified. These included class of building, average internal height, mezzanines and fire-source features. The researcher proposed solutions to address these challenges. Some solutions required *Ignis* additional calculations, such as the average internal height and mezzanines. Determining the class of building was the only task that required users to complete additional set-up activities prior to commencing code-checking activities. This involved users having to set and/or confirm room names for the class of building (The researcher predefined several parameters for each classification.). Once the class of building had been set up, users did not need to repeat this work for subsequent code-checking activities. The interviewed accredited certifiers verified these solutions during the evaluation process. These solutions are not elegant and may be subject to future development.

7.4.2 Evaluation techniques

Within the Design Science methodology research, the methods used to evaluate diverse artefacts can be different as each artefact has various specific features and characteristics (Hevner, A. and Chatterjee 2010). In this study, the researcher adopted a range of BIM models as well as demonstration and interview tchniques to evaluate *Ignis* for different purposes (Pries-Heje et al. 2008, Venable, John et al. 2012). These BIM models evaluate the purpose-built artefacts in a contrived and formulated manner. In the contrast, demonstrations and interviews explore the performance of artefacts in its real environment.

 # Varied BIM models

The researcher adopted testing methods using a range of purpose-built models. These models were built by *Autodesk® Revit®* 2014 to examine specific rules. For example, a two-storey building was tagged as a warehouse for the top storey. Its internal height was six metres and the building needed to be determined as a three-strorey class 7b building. The artificial method was used to examine whether the rules were designed effectively and were able to produce results consistently. The evaluation results of *Ignis* supported the next evaluation activity using demonstrations and interviews.

 # Demonstrations and interviews

The researcher engaged accredited certifiers and architects in the later evaluations using demonstration and interview techniques. This evaluation work was structured into three sequential stages: preliminary (with one accredited certifier), first (with six accredited certifiers) and second primary evaluation works (with a group of fifteen architects and two individual architects). Demonstrations firstly used slides (see Appendix 5) to explain the structure of this study (emphasizing rule designs); followed by examining *Ignis* using a sample model of a school provided by *Autodesk® Revit®* 2014. The participants were able to operate *Ignis* for code-checking activities, produce reports and interact with BIM models through the reports.

The demonstrations enabled participants to understand and experience the ways *Ignis* operated. This allowed the participants to provide feedback during the interview stage. The researcher prepared interview questions that enabled the participants to assess *Ignis* against four topics: system structures, code-checking rules, report information and system interfaces. Each topic contained different selected evaluation criteria (e.g. functionality and efficacy). The feedback from the participants was collected and analysed against the evaluation criteria. The evaluation results were positive and therefore these evaluation techniques can be seen as effective means of evaluating *Ignis*-like systems.

7.4.3 Outcomes of Design Science methodology research

Within the Design Science methodology research, knowledge and/or contributions can be explored through the development process of purpose-built artefacts (Hevner, A. and Chatterjee 2010). Five research outcomes: constructs, models, methods, instantiations and improved theories have been discussed in section 4.4.2 (at page 73). These five outcomes have been discussed throughout the *Ignis* development process and are explained below.

 # Constructs

Constructs may be defined as 'the conceptual vocabulary of a problem/solution domain' in Design Science methodology research (Vaishnavi and Kuechler 2015: 13). Constructs were formed from the problem conceptualization process and refined throughout the development process (of artefacts). In this study, the research problem emphasized building design compliance issues against the BCA. In Australia, building designs must comply with the BCA before the commencement of construction works. In Australia, certifying authorities or consultants are rarely engaged to advice about building designs during the design process (prior to construction works). Building designs are thus difficult to assess for code compliance before submitting to certifying authorities. In addition, because some BCA clauses are open to interpretation, accredited certifiers may determine whether building designs comply based on their personal experience. Their assessments may result in building designs not complying with building regulations, resulting in schedule delays and budget overruns. This study proposed the creation of an artefact, a computer aided code-checking system, to address the research problems. BIM technology was seen as an optimal vehicle for this study. BIM-CCS can be seen as a computerized certifier. Project stakeholders can engage a BIM-CCS to commence design compliance assessments during the design process. This demonstrates considerable potential and is supported by relevant studies. The problems and solutions identified contribute to indicate constructs for this study as:

- Certifying activities in design process,
- Provided a mechanism for generating assessment results,

- A computer aided code-checking system (BIM-CCS)

Models

Models may be represented as ‘a set of propositions or statements expressing relationships between constructs’ (Vaishnavi and Kuechler 2015: 13). Within the identified constructs, the BIM-CCS performed as the core construct connecting to the others. As BIM has been integrated in design processes by project stakeholders to develop their building designs, it was pragmatic to use BIM as a medium to develop a code-checking system. The BIM-CCS can be seen as a virtual certifier performing certifying activities in the design process for project stakeholders. The code-checking rules built into the BIM-CCS perform a series of decision-making processes against model parameters. The decision-making process designed for each rule is fixed and cannot be revised or manipulated by users. It enables them to coordinate and produce consistent assessment results for project stakeholders.

Methods

Methods are ‘a set of steps used to perform a task – how-to knowledge’ (Vaishnavi and Kuechler 2015: 13). Methods can be seen as guidelines for creating the BIM-CCS. In order to create *Ignis*, this study was based on the structure in Chapter 5 (at page84). This begins with interpreting the BCA clauses to inform the rule designs. Once rules were designed and created, project stakeholders can execute code-checking activities to assess their designs for compliance. The BIM-CCS then produced results of reports identifying whether or not the building designs complied. Project stakeholders can then revise designs in accordance with the reports. Project stakeholders can repeat the process of assessment and revision until their designs comply with all code requirements.

Instantiations

The fourth outcome is ‘Instantiations’. It ‘operationalizes constructs, models and methods’ (Vaishnavi and Kuechler 2015: 13). *Ignis* was the final production, realizing the aim of this study. The rules in *Ignis* were developed to read model parameters. This study firstly interpreted the BCA clauses to inform rule designs. Two semantic analysis methods, DL and RASE, were used to identify the hierarchical structure of codes as well as to interpret the requirements of each code. This enabled the researcher to explore and match BIM parameters to the identified code requirements. The decision-making processes for each rule could then be designed.

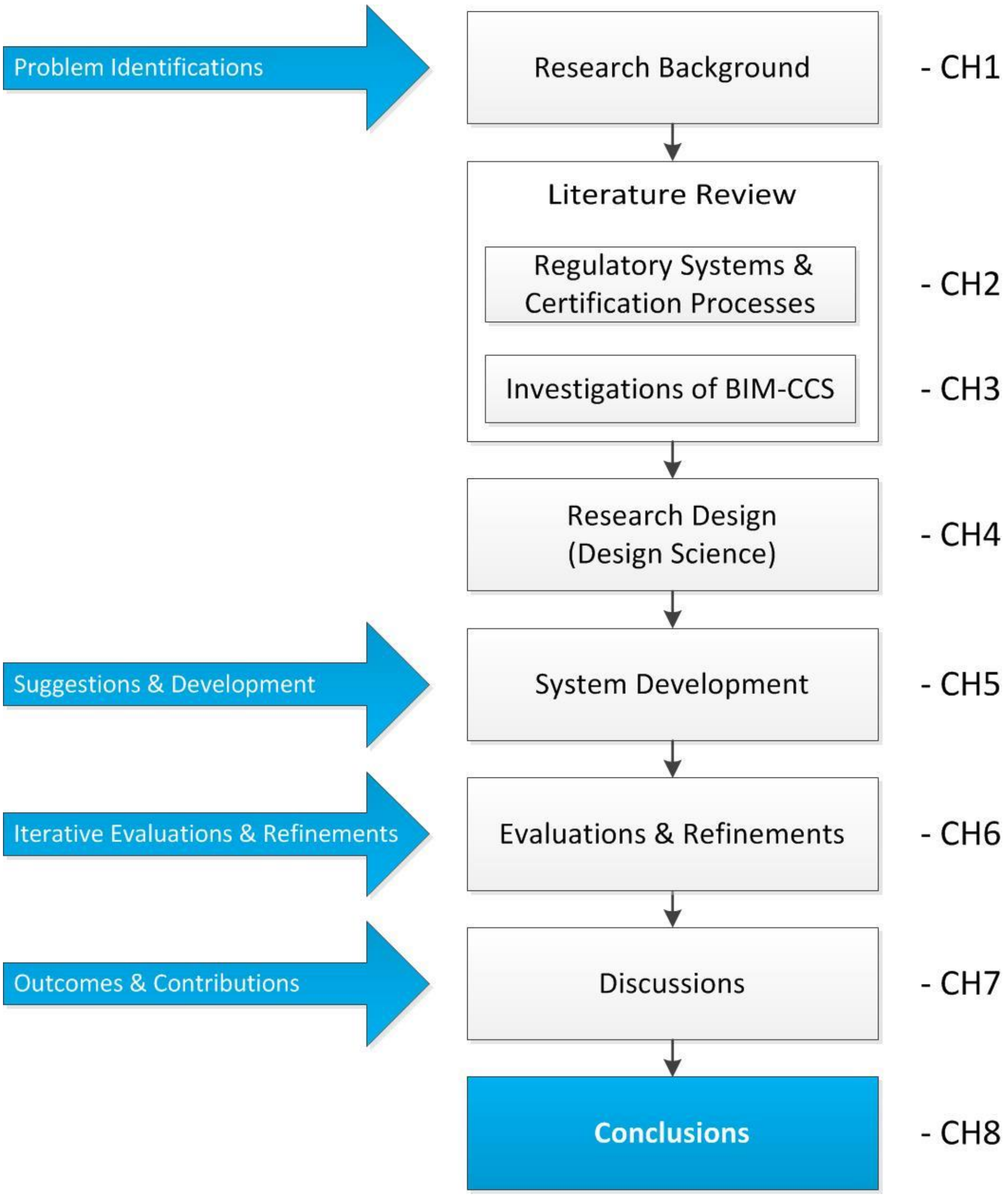
Ignis was then evaluated through demonstrations and interviews with accredited certifiers and architects. Accredited certifiers participated in the evaluations and confirmed that the code-checking rules replicated the certifying work of accredited certifiers. Through demonstrations, the participants could understand how the rules operated and results were produced. This confirmed *Ignis*’ abilities to perform consistent assessment results for project stakeholders. *Ignis* was then evaluated by architects for implementing certifying activities in design process. Architects understood the structure of *Ignis*, how the rules operated, what formats the assessment reports were presented in and how they could interact with building designs through the reports.

Improved theories

The final outcome was an improved theory, emphasizing ‘artefact construction as analogous to experimental natural science, coupled with reflection and abstraction’ (Vaishnavi and Kuechler 2015: 14). Throughout the development process, *Ignis* has been developed following Design Science guidelines. This provided a framework for BIM-CCS development, particularly in relation to the methods of creating code-checking rules and evaluating BIM-CCS. *Ignis* has been verified to be an effective means of addressing the research gaps. *Ignis* is an example in the BIM-CCS domain, contributing to BIM-CCS structures, rule designs, report demonstrations and interface designs. A theory generated from the entire development process of *Ignis* is:

Incorporating BIM-CCS into design processes can provide consistent and efficient code compliance assessments for building designs and thereby secure building designs complying with the BCA through the iterative process of assessment and revision.

8 CONCLUSION



8.1 Introduction

This chapter concludes this study by addressing to the identified research problems, aims and objectives.

8.2 Research outcomes for the research objectives

The research objectives were formed through the accumulated key issues (from Chapter 2 and 3) to achieve the research aims. The research outcomes addressing the objectives are discussed below.

Obj. 1 To develop a structure for *Ignis* specific to Section C Fire Resistance of BCA for commercial buildings.

This study has developed the BIM-CCS, *Ignis*, to assess BIM models against the fire resistance codes (Section C of the BCA) and commercial buildings (Class 5 to 9). *Ignis* comprises four components including the Informer, Ruler, Communicator and Reporter. The function of each component is described below.

Informer: This indicates the BIM model information created by project stakeholders. This study adopted Revit models to provide information/parameters for code-checking activities. The reasons for choosing Revit models included *Autodesk*® *Revit*® having a significant market share compared to other software extensions and its strong supportive abilities for plugin development. Although many BIM-CCSs (surveyed in section 3.6 at page 44) highlight the interoperability of IFC schema models (Eastman, C. et al. 2009, Tan et al. 2010, Yang and Li 2001), many studies agree that parametric and/or geometric objects may be lost when IFC-based models are exported and/or imported to other BIM software packages (Greenwood et al. 2010, Pazlar T 2008).

Ruler: This represents the process of interpreting code clauses to inform rule designs. Semantic analysis methods, RASE and DL, were used to identify the key requirements of code clauses and their hierarchical relationships (Hjelseth, Eilif and Nisbet, Nick 2011, Omari and Roy 1993). The identified requirements were then used to explore the model parameters that they satisfy. If the required parameters are not provided, additional calculations and/or manual works are needed (such as calculating the average internal height and identifying mezzanines). These solutions were examined for effectiveness through a series of evaluations.

Communicator: This is a platform that enables BIM information and rule requirements to be communicated. In this study, *Ignis* has been built in *Autodesk*® *Revit*® 2014. Revit allows rules to be embedded within it and can therefore read model parameters directly. An additional benefit of using Revit is that users can seamlessly modify their designs following code-checking activities. In contrast, IFC-based BIM-CCSs may need successive data exportation and importation activities to trial design changes.

Reporter: This produces reports in accordance with the assessment results from the communicator. *Ignis* reports can be obtained in both textual and visual formats. The textual reports are formatted similar to practical industry reports and provide assessment results clause by clause. The visualization reports allow users to interact with and locate identified problematic objects.

Obj. 2 To enable an Ignis prototype to perform effective code-checking activities.

The *Ignis* rules were designed in accordance with the results of semantic analysis methods, RASE and DL. These methods assisted the researcher to outline the decision-making process for each rule in a logical manner. The developed rules were firstly examined for effectiveness by a range of simple models. In addition, the *Ignis* code-checking rules were assessed by a number of accredited certifiers in preliminary and first primary evaluations.

The evaluation process included demonstrations and interviews. The researcher firstly introduced the decision-making process for each building code using graphical slides. Afterwards, a sample model was used in an demonstration. Accredited certifiers interacted with *Ignis* to conduct code-checking activities and produce assessment results. The demonstrations enabled the participants to understand how code-checking rules operated to determine whether building elements complied or did not comply and how assessment results were presented in reports.

The evaluation results verified the efficacy of the code-checking rules and confirmed that *Ignis* provided consistent assessment results for building designs. However, it was identified that some BCA clauses are written in an ambiguous manner and can be open to different interpretations. This compromised the consistency of assessment activities. However, if BCA codes are consistently worded, *Ignis* is able to perform consistent assessments.

Obj. 3 To investigate the manner in which project stakeholders use *Ignis* to facilitate design activities during the design process.

In the last stage of the evaluation process, a number of architects were invited to assess *Ignis*. The same evaluation methods were used in this stage. The participants appreciated that *Ignis* enabled them to assess their building designs during the design process. They highlighted that integrating *Ignis* into the design process enabled them to inform project stakeholders what had not been done rather than what had been done. They could therefore take action and revise their designs in accordance with the comments provided by *Ignis*. For example, when the FRL of a wall does not reach the requirements of the BCA, *Ignis* is able to recommend the minimum FRL required as well as inform users that the wall does not comply. Those interviewed were highly supportive of this feature*Ignis*.

In addition, the participants highlighted that using *Ignis* in the design process allowed them to improve coordination of building designs, particularly when stakeholders joined or left. This was because the *Ignis* reports can assist new members to gain an overall understanding of the project. Moreover, the participants indicated that their awareness of the BCA can be improved as the *Ignis* reports are formatted clause by clause, enabling them to identify which clauses had not been complied with.

8.3 Research outcomes for the research aim

The aim of this research is stated in section 1.6 (at page 7) as:

To develop a BIM-CCS that enables building designs to be checked for compliance against the BCA.

The objectives described in previous section were constructed to achieve the research aims for this study. The outcomes achieved address the research aim.

The structure of *Ignis* was firstly shaped according to the BIM-CCS literature survey. The entire structure of *Ignis* was established on *Autodesk*® *Revit*® 2014. Revit provides an API that enables programmers to develop plugins that can extend Revit to deal with various complex design work. *Ignis* is embedded in Revit and can directly read model information for code-checking activities. This enables project stakeholders to seamlessly revise their designs on the same platform. This allows design model information to be refined without having to transferring model data (Several studies identified the need for models to be exchanged between BIM software packages, resulting in lost parameters and/or geometry objects.)

In addition, code-checking rules were developed using two semantic analysis approaches (RASE and DL). In addition to identifying the BIM parameters required, these methods assisted in clarifying rule decision-making processes and hierarchical relationships. Several instances were identified where BIM parameters could not be identified. Additional calculations and/or manual work had to be conducted to overcome/mitigate these challenges. The *Ignis* code-checking rules have been assessed and verified for effectiveness in the preliminary and first primary evaluations separately.

Finally, *Ignis* was evaluated by seventeen architects (including a group of fifteen architects and two individual artitects). These participants appreciated that incorporating *Ignis* into design processes can facilitate design compliance activities in an efficient and consistent manner. The *Ignis* reports are able to inform users whether building designs comply or not in textual and visual reports. These *Ignis*reports are formatted clause by clause and can locate problematic objects and provide suggestions to address non-compliant design issues. These research outcomes provide evidence that the research aim of this study has been comprehensively met.

8.4 Research outcomes for the research problems

Research problems were identified in section 1.2 (at page 3) as:

- **Poor coordination of design drawings between project stakeholders and certifying authorities can result in repetition certification work.**

BIM technology provides a platform that allows project stakeholders located in different places and/or work in different time zone to collaborate on the same design projects. It is possible for one stakeholder to modify model parameters and for others to update models synchronously. Using BIM models for design and certification works can reduce the time taken in manual documentation work for updates. Moreover, errors and fragmented data may arise from manual activities. These can be mitigated and thereby strengthen the coordination of documents.

- **Stakeholders' lack of knowledge of the BCA impedes them from obtaining approval of their building designs.**

Through the evaluation processes, *Ignis* has been verified as being able to assist project stakeholders to assess their designs for code compliance during the design process. The role of *Ignis* can be seen as a computerized certifier that can be engaged during various design stages. *Ignis* can produce assessment results in textual and visual reports. These reports are formatted in a clause by clause style. The *Ignis* reports inform users about design issues and provide suggestions about the issues identified. The architects interviewed appreciated this and observed that their awareness of the BCA would be enhanced through such iterative assessment activities.

- **Building codes are open to different interpretations and may result in inconsistent certification outcomes.**

This study adopted the RASE and DL methods to semantically analyse fire resistance code clauses. These methods can help identify the requirements of each code and allowed the researcher to explore which BIM parameters match the identified requirements. This enabled the researcher to design decision-making processes for each code in a systematic and consistent manner. These rule designs have been verified by accredited certifiers for their accuracy. However, a significant issue the interview participants identified is that some building codes are written in an open-interpreted manner. This may impede the consistency of *Ignis* assessments. If it were possible to interpreted building codes consistently, *Ignis* can therefore provide consistent assessments of building designs.

8.5 Suggestions for future development

Throughout the development of *Ignis*, several challenges were identified as possible future developments.

8.5.1 Consistent BCA interpretations

The BCA codes need to be revised and simplified. Redundant clauses need to be removed. This study has adopted RASE methods to identify the needs of each code. DL methods were adopted to identify their hierarchical relationships. These methods have been verified to assist design consistent decision-making process for code clauses. However, several codes are not clearly defined and solutions still need to be found so that they can be incorporated in BIM-CCS. For example, code C1.2 (b) (ii) involves complex calculations to determine whether or not a storey needs to be counted when it intersects with the finished ground level. Accredited certifiers determine this by relying on elevation and section drawings. However, these drawings may provide different and/or contrasting information that may result in different assessment results.

This is supported by the ABCB reform plan for building regulations. This plan identifies goals that are to enhance awareness and adherence to the NCC, improve building outcomes through code compliance activities and increase the economic benefit in the construction industry. One of the approaches of achieving these goals is 'reviewing the NCC to remove unnecessary, superseded or duplicative regulation' (Australian Building Codes Board 2014: 2).

8.5.2 Engaging multiple disciplines in BIM-CCS design

Through the *Ignis* development process, several challenges were identified that require the engagement of multiple disciplines. This particularly highlights the need for information provide by other disciplines to successfully execute code-checking activities. For example, BIM vendors may need parameter templates (e.g. parameters for building classifications and mezzanines) specific to code-checking activities. Moreover, fire resistance codes relate strongly to the materials used. A pre-defined material library that incorporates parameters for fire resistance would be useful to stakeholders. This may require project stakeholders to manually set parameters for building materials. However, such manual settings may be error-prone and result in ineffective assessment results. To solve the problem, materials suppliers need to provide effective libraries of materials that project stakeholders can directly refer to during their design development process. This would ensure the integrity of the required information for code-checking activities.

8.5.3 Design process and creativity

The evaluation results supports the aim of this research that code compliance activities need to involve in building designs at the early stages (Ralph 2001). It is conceivable that stakeholders might work differently if they were able to check their designs for compliance at various stages of their design activity. This also has the potential to alter the ways stakeholders design. Once the assessment results identify design issues, project stakeholders then can explore ways to solve these issues in creative ways.

Moreover, it is worth to exploring the productivities, performance and collaboration of project stakeholders when incorporating *Ignis* in the design process. Issues relating to cost, schedule and variations *Ignis* also warrant further investigation.

8.6 Personal reflection

As a product design practitioner, I was able to take an objective stance in investigating the problems and opportunities of the Australian construction industry. Before enrolling as PhD candidate I worked as a design engineer and project manager in product design and manufacturing for four years. During this period I was responsible for coordinating product information and streamlining processes between stakeholders, engineers and manufacturers using CAD and project lifecycle management technologies. This experience was very similar to stakeholders incorporating BIM technology in design processes to strengthen communication and collaboration. This foundation enabled me to investigate BIM extensions specific to code compliance for the Australian construction industry.

Throughout the entire research process, I participated in several formal and informal meetings with local councils, building design companies, BIM vendor representatives and many academic BIM experts. This helped me gain an understanding of the Australian regulatory system and the uptake of BIM by the Australian construction industry. In turn, this assisted me in identifying the research problems for this study. In the *Ignis* development process, the Design Science methodology provided a framework that shaped the ways of creating *Ignis* systematically. The iterative process of development and evaluation emphasized by the Design Science methodology enabled *Ignis* to be refined in an effective manner.

The entire research process led me to gain comprehensive knowledge and strong abilities in BIM technologies and Design Science research. This will definitely assist me in exploring and solving design process related issues that project stakeholders encounter in the future.

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APPENDIX 1 ETHICS

HUMAN RESEARCH ETHICS COMMITTEE

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Progress Report Acknowledgement

To Chief Investigator or Project Supervisor:	**Associate Professor Willy Sher**
Cc Co-investigators / Research Students:	**Mr Shan-Ying Shih** **Doctor Helen Giggins** **Doctor Sittimont Kanjanabootra**
Re Protocol:	**Using experimental simulations to assess the efficacy of a Building Information Modelling (BIM) enabled code-checking system (BIM-CCS) for Australia**
Date:	**17-Feb-2015**
Reference No:	**H-2014-0093**

Thank you for submitting your **Annual Progress Report** to the Human Research Ethics Committee (HREC) in relation to the above protocol.

Your report has been accepted and your HREC approval for the above research remains valid. Continuation of this approval will again be subject to the provision of an annual progress report by the due date approximately one year from now.

The timely submission of your report is greatly appreciated.

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APPENDIX 2 RULE DESIGNS USING PROCESS MODELS

C1.1 Type of construction required

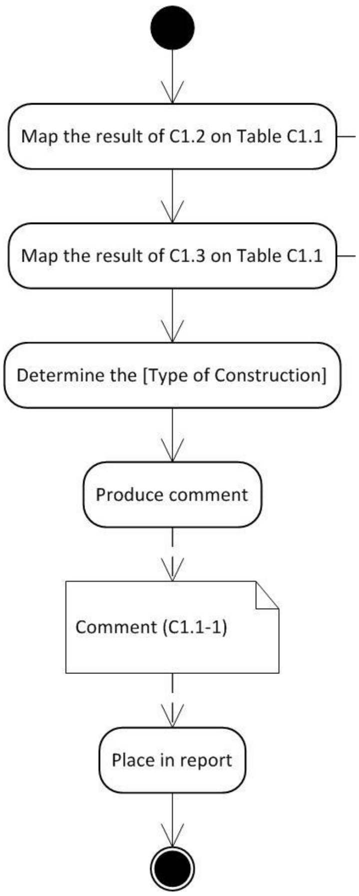
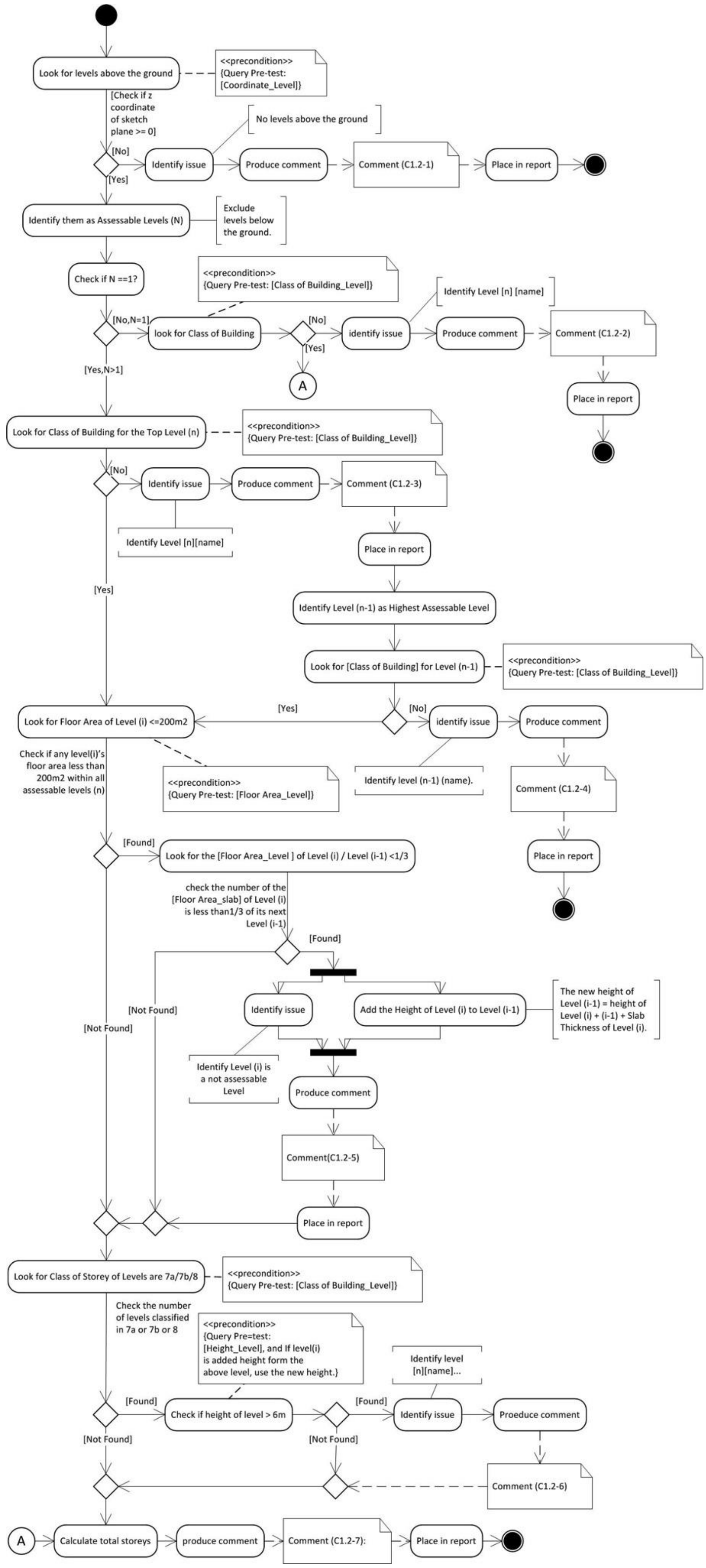


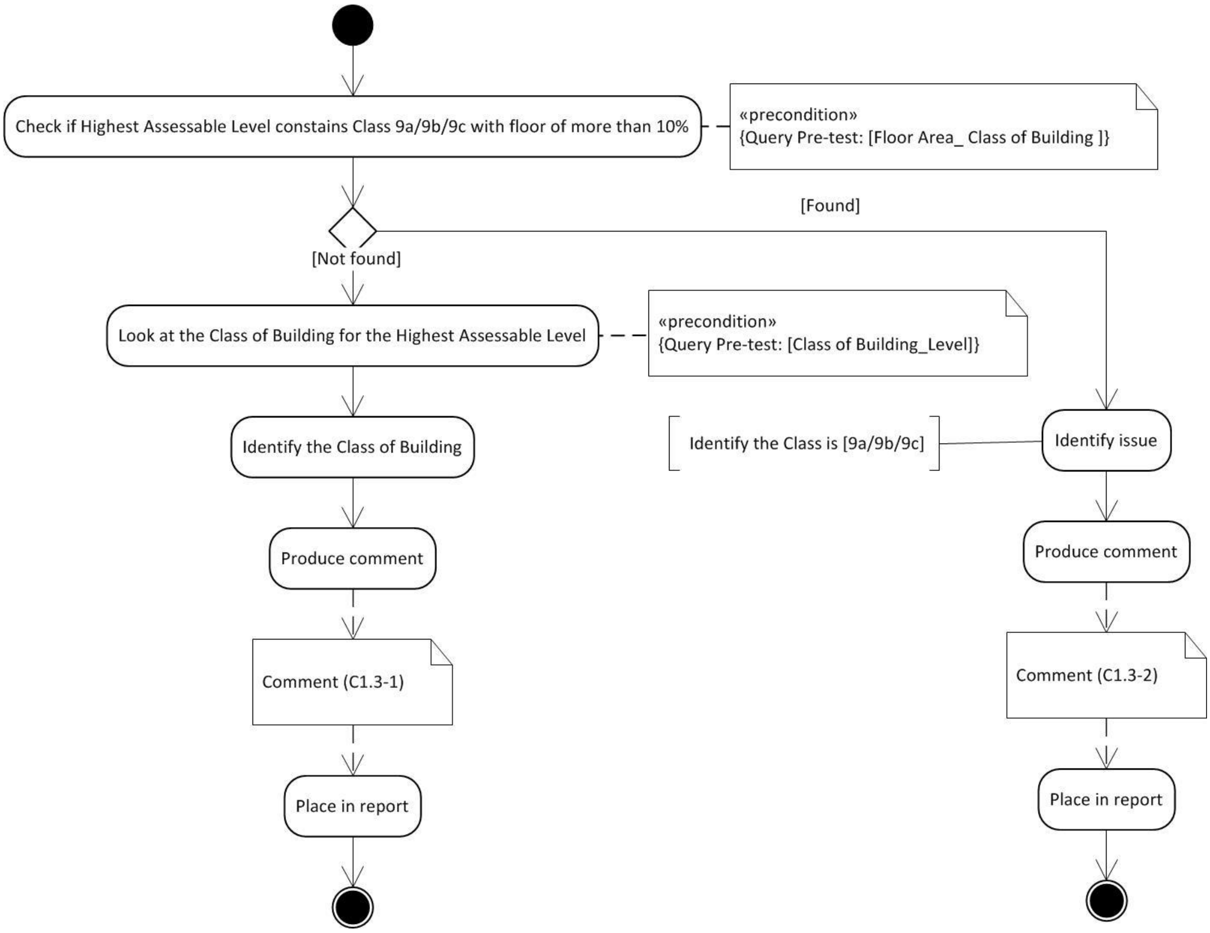
Table C1.1 TYPE OF CONSTRUCTION REQUIRED

Rise in storeys	Class of building	
	2, 3, 9	5, 6, 7, 8
4 OR MORE	A	A
3	A	B
2	B	C
1	C	C

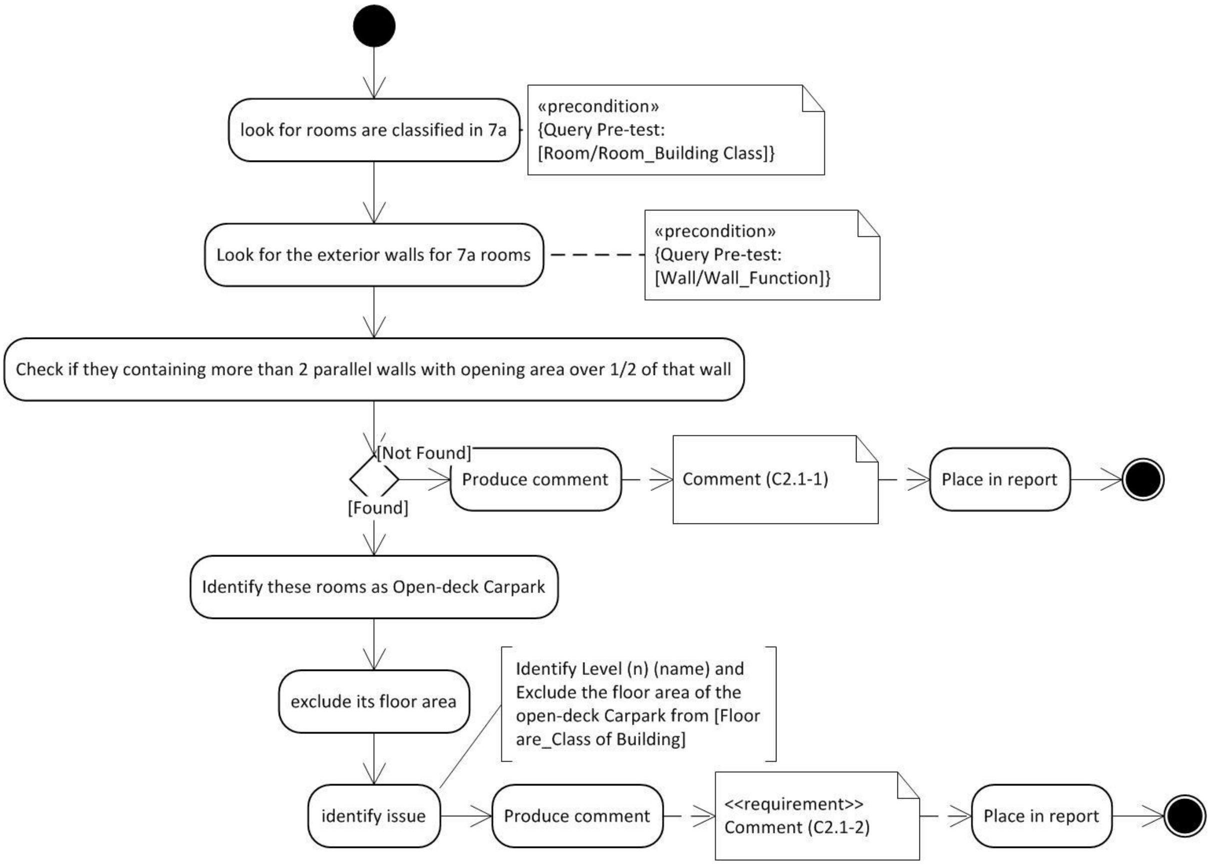
C1.2 Calculation of rise in storeys



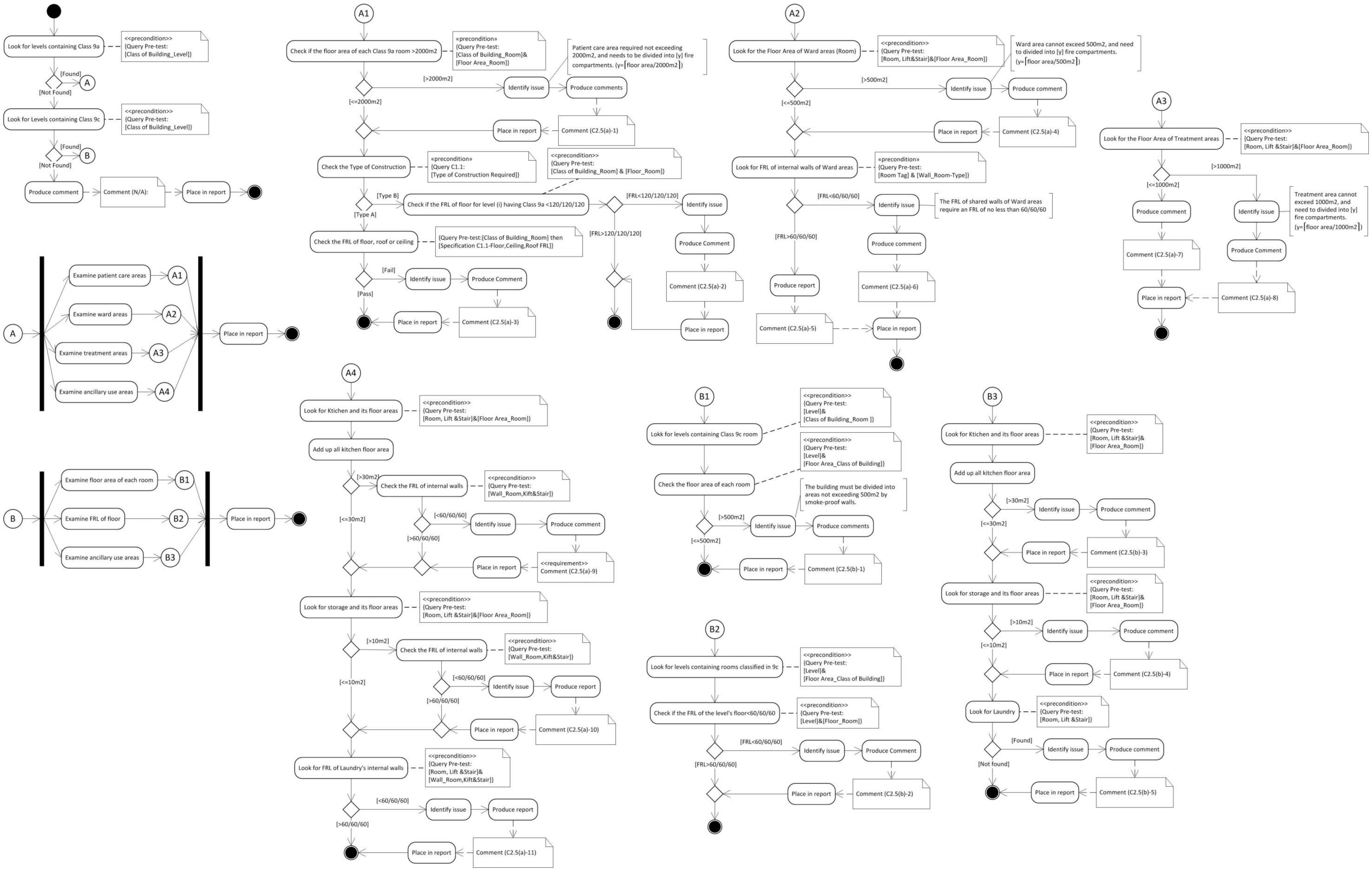
C1.3 Buildings of Multiple Classification



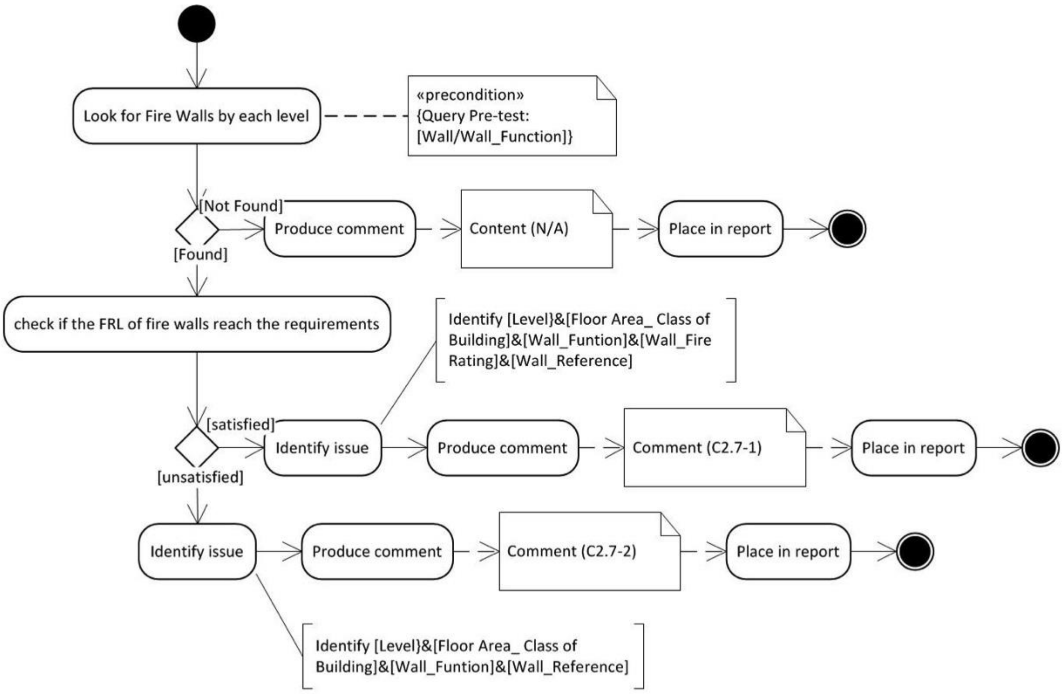
C2.1 Application of Part



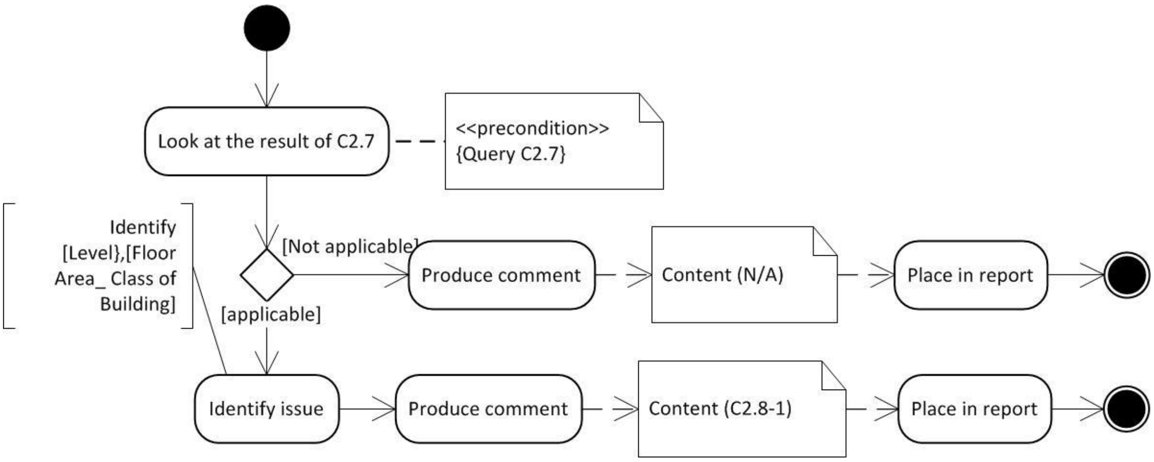
C2.5 Class 9a and 9c buildings



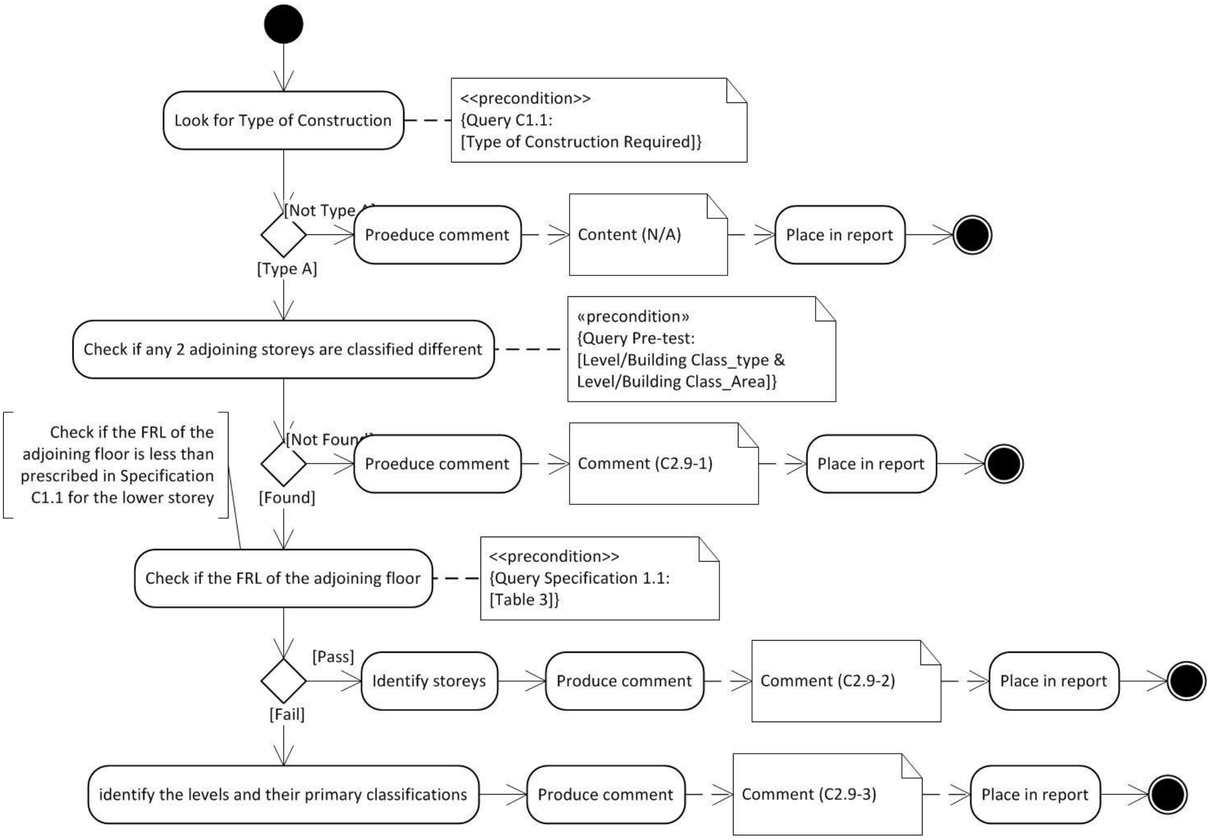
C2.7 Separation by fire walls



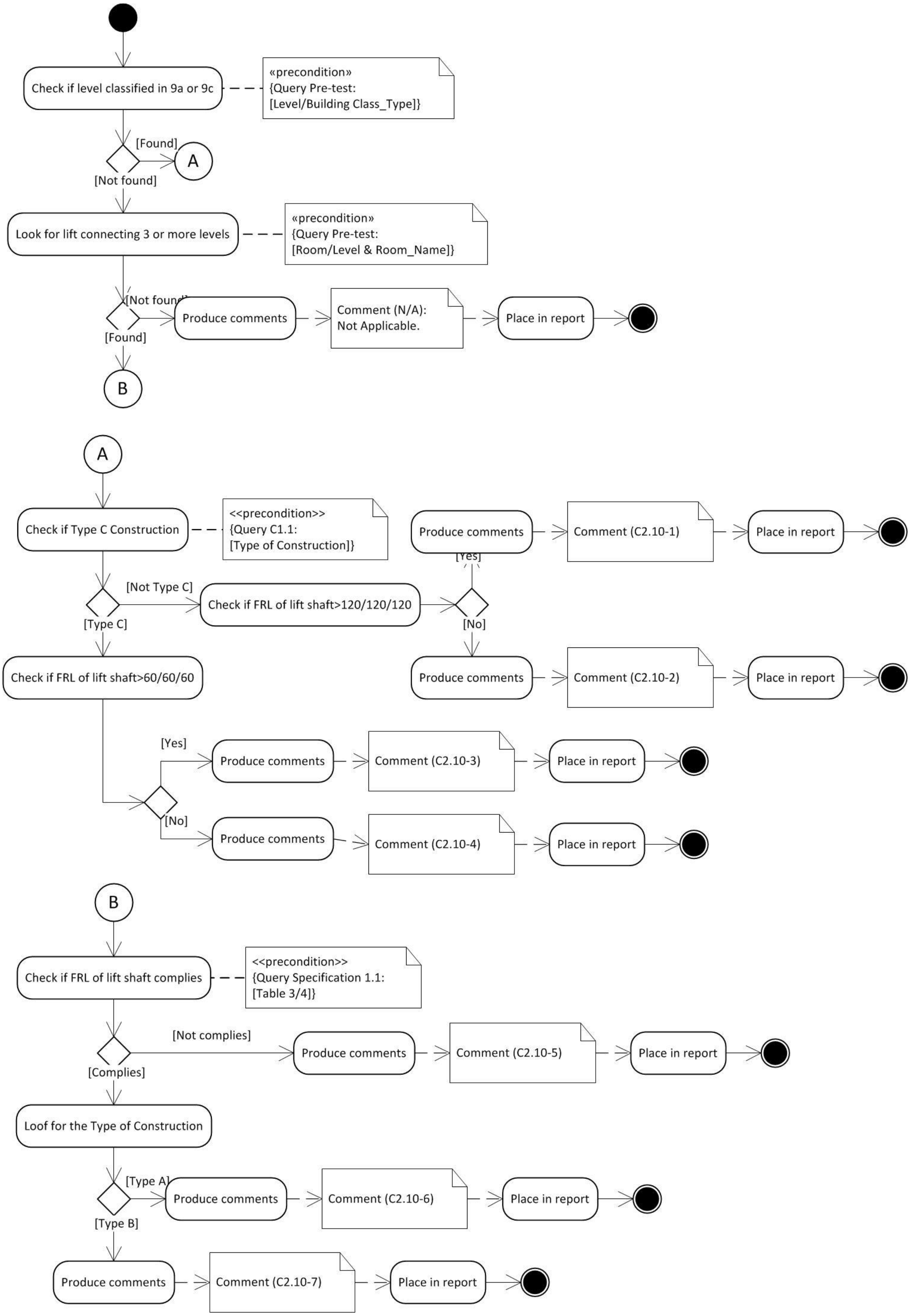
C2.8 Separation of classifications in the same storey



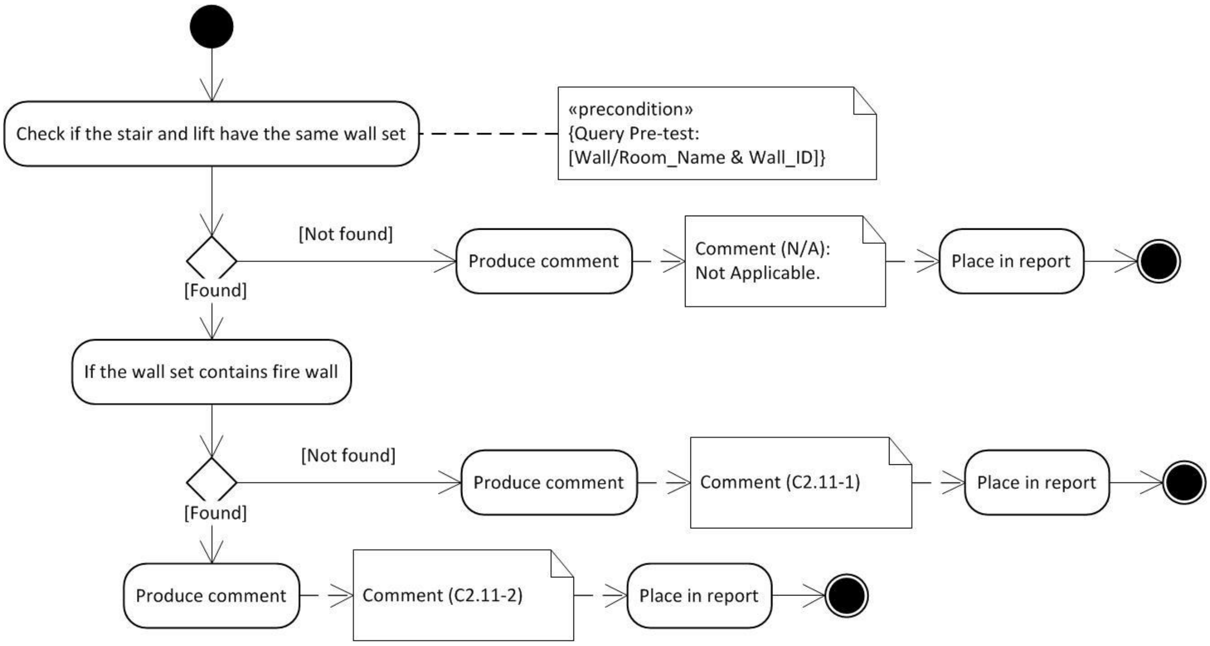
C2.9 Separation of classifications in different storeys



C2.10 Separation of lift shafts



C2.11 Stairways and lifts in one shaft



APPENDIX 3 CODE ELEMENTS ANALYSIS

Legend:

O=available BIM parameters

X=unavailable BIM parameters

A=additional calculations

Object	**Code**	**RASE**	**O**	**X**	**A**	**Information/Reference**
Physical objects						
Air-handling system (ductwork)	C1.10(a)(iii)	A	V			Refer to specification D1.10
	C1.10(c)(x)		V			Refer to C1.10(a)
Airport terminal	C1.8(a)(ii)	S		V		
Allotment	C1.2(a)(ii)	S	V			
	C2.3(c)	A	V			
	C2.4(a)	A	V			
	C2.4(b)(v)	A	V			
Ancillary use area	C2.5(a)(v)	A			V	Wall FRL≥60/60/60 to separate patient care area
	C2.5(b)(iv)	A			V	Separated by smoke proof walls
Atrium	C1.0(a)(ii)	S		V		Refer to Part G3
	C2.0(a)(ii)	S		V		Refer to Part G3
	C2.0(b)(ii)	S		V		Refer to Part G3
	C2.2(a)	A		V		Refer to Part G3
	C2.2(b)	S		V		
	C2.2(c)	S		V		
Blind	C1.10(c)(xiii)	A	V			Refer to Specification H1.3
Bus station	C1.8(a)(ii)	S		V		
Carpark	C2.1(a)	A		V		With a sprinkler system complying with Specification E1.5
	C2.1(a)	A		V		Open-deck
	C2.6(b)(i)	E		V		Open-deck

Object	Code	RASE	O	X	A	Information/Reference
	C2.8(c)	A		V		Refer to Table 3.9, 4.2, 5.2 of Specification C1.1
Ceiling	C1.2(b)(ii)	A	V			
	C1.10(a)(ii)	A	V			Ceiling linings, Refer to specification D1.10
	C1.10(a)(viii)	A	V			
	C2.5(a)(iv)(A)	S		V		Refer to Specification C1.1
	C2.5(a)(viii)	A		V		Resistance to the incipient spread of fire ≥60min
Cement render	C1.10(c)(i)	A	V			Refer to C1.10(a)
Ceramic tile	C1.10(c)(i)	A	V			Refer to C1.10(a)
Changing rooms	C1.7(a)	E			V	
Column	C1.8(b)	S	V			Steel
	Spec C1.1 Table 3	S	V			External
	Spec C1.1 Table 3.9	S	V			External
	Spec C1.1 Table 4	S	V			External
	Spec C1.1 Table 4.2	S	V			External
	Spec C1.1 Table 5	S	V			External
	Spec C1.1 Table 5.2	S	V			External
Concrete	C1.10(c)(i)	A	V			Refer to C1.10(a)
Cover-plate	C1.10(c)(vi)	A	V			Refer to C1.10(a)
Cupboard	C1.10(c)(xii)	A	V			Refer to C1.10(a)
Curtain	C1.10(c)(xiii)	A	V			Refer to Specification H1.3
Damp-proof course	C1.10(c)(vii)	A	V			Refer to C1.10(a)

Object	Code	RASE	O	X	A	Information/Reference
Damp-proof flashing	C1.10(c)(vii)	A	V			Refer to C1.10(a)
Damp-proof caulking	C1.10(c)(vii)	A	V			Refer to C1.10(a)
Damp-proof sealing	C1.10(c)(vii)	A	V			Refer to C1.10(a)
Door	C1.10(c)(v)	A	V			Timber-faced solid-core door; Timber-faced fire door, Refer to C1.10(a)
Doorway	C2.5(a)(viii)	A	V			FRL≥-/60/30
	C2.5(b)(vi)	A	V			-/60/30 fire doors
Electricity network substation	C2.1(b)	A		V		Class 8
Electrical components	C1.10(c)(xi)	A	V			Wiring, Refer to C1.10(a)
	C1.10(c)(vi)	A	V			Electrical switch, Refer to C1.10(a)
Emergency exit sign	C1.10(c)(xi)	A	V			Refer to C1.10(a)
Escalators	C1.10(a)(vi)	A	V			Refer to specification D1.12
Face (diffuser) plate	C1.10(c)(x)	A	V			Refer to C1.10(a)
Fire brigade vehicles	C2.4(b)(iv)	A		V		
Fire compartment	C2.2(a)	A			V	
	C2.2(b)	A			V	
	Table 2.2	S			V	Floor area
	Table 2.2	S			V	Volume
	C2.3(a)	A			V	Floor area ≤18000m2 or Volume≤108000m3
	C2.3(b)	A			V	Floor area ≥18000m2 or Volume≥108000m3
	C2.5(a)(i)	A			V	≤2000m2
	C2.5(a)(iv)	A		V		

Object	Code	RASE	O	X	A	Information/Reference
	C2.5(b)(ii)	A			V	Separated by fire walls, Refer to C2.7 and Specification C1.1
Fire-isolated passageway	C1.8(a)(ii)	S		V		
Fire-isolated ramp	C1.8(a)(ii)	S		V		
Fire-isolated stairway	C1.10(a)(vi)	A	V			Refer to specification D1.12
Fire-resisting covering	C1.8(b)	A	V			
Fire-source features	Spec C1.1 Table 3	S			V	Type A
	Spec C1.1 Table 3.9	S			V	Type A Carpark
	Spec C1.1 Table 4	S			V	Type B
	Spec C1.1 Table 4.2	S			V	Type B Carpark
	Spec C1.1 Table 5	S			V	Type C
	Spec C1.1 Table 5.2	S			V	Type C Carpark
Floor	C1.2(d)(i)	S	V			
	C1.2(d)(ii)	S	V			
	C1.10(a)(i)	A	V			Floor linings, Refer to specification D1.10
	C1.10(a)(i)	A	V			Floor coverings, Refer to specification D1.10
	C1.10(a)(viii)	A	V			
	C2.2(a)	A	V			
	C2.2(b)	A	V			
	C2.3(a)	A	V			Floor area ≤18000m2
	C2.3(b)	A	V			Floor area ≥18000m2
	C2.5(a)(i)	A	V			Patient care area ≤2000m2
	C2.5(a)(ii)(A)	A	V			Ward area≤1000m2
	C2.5(a)(ii)(B)	A	V			Ward area≤500m2
	C2.5(a)(iv)(A)	S			V	Refer to Specification C1.1

Object	Code	RASE	O	X	A	Information/Reference
	C2.5(a)(iv)(B)	S			V	FRL≥120/120/120
	C2.5(a)(vii)	S	V			
	C2.5(b)(i)	S	V			≤500m2
	C2.5(b)(ii)	S	V			FRL ≥ 60/60/60
	C2.5(b)(iii)	S	V			Refer to C2.5(b)(ii)
	C2.5(b)(v)	S	V			Kitchen≥30m2, Storage room≥10m2
	C2.6(a)(i)	S			V	Intervening floor
	C2.7(c)	S	V			FRL ≥fire wall
	C2.9(b)(i)	S	V			
	C2.9(b)(ii)	S	V			FRL≥30/30/30
	Spec C1.1 Table 3	S	V			Type A
	Spec C1.1 Table 3.9	S	V			Type A Carpark
	Spec C1.1 Table 4	S	V			Type B
	Spec C1.1 Table 4.2	S	V			Type B Carpark
	Spec C1.1 Table 5	S	V			Type C
	Spec C1.1 Table 5.2	S	V			Type C Carpark
Ground	C1.2(a)	A	V			
	C1.2(b)(ii)	A	V			
	C1.2(c)	A	V			
Ground moisture barrier	C1.10(c)(vii)	A			V	Refer to C1.10(a)
Guard houses	C2.4(a)(iv)	A		V		
Handrail	C1.10(c)(iv)	A	V			Timber, Refer to C1.10(a)
Heating	C1.2(b)(i)	S	V			
	C2.2(b)	S	V			
Hyperbaric	C2.5(a)(vi)				V	Refer to C2.5(a)(v)

Object	Code	RASE	O	X	A	Information/Reference
Indoor sports stadiums	C1.1(a)(iii)	A		V		
	C1.7	A		V		
	C1.8(a)(ii)	A		V		
Joinery unit	C1.10(c)(xii)	A		V		Refer to C1.10(a)
Kitchen	C2.5(a)(vi)	A	V			Refer to C2.5(a)(v), Floor area≥30m2
	C2.5(b)(v)		V			Floor area≥30m2
Lacquer	C1.10(c)(viii)	A	V			Refer to C1.10(a)
Laminated material	C1.12(f)	A	V			Non-combustible & adhesive layer ≤ 1mm & total thickness including adhesive layer ≤ 2mm & total thickness including Spread-of Flame index ≤ 0 and Smoke-Developed Index ≤ 3
Lath	C1.12(b)	A	V			Perforated gypsum
Laundry	C2.5(a)(vi)	A	V			Refer to C2.5(a)(v)
	C2.5(b)(v)		V			
Lift equipment	C1.2(b)(i)	S	V			
	C1.10(a)(iv)	A		V		Lift cars, Refer to specification D1.10
	C2.2(b)	S		V		
Lightweight construction	C1.8	A			V	Refer to specification C1.8
Mezzanines	C1.2(d)(i)	A			V	
	C1.2(d)(ii)	A			V	
Moving walkways	C1.10(a)(vi)	A		V		Refer to specification D1.12
Open space	C2.4(a)	A		V		
Openspectator stands	C1.1(a)(iii)	A		V		

Object	Code	RASE	O	X	A	Information/Reference
	C1.7	A		V		
	C1.8(a)(ii)	A		V		
	C2.1(a)	A		V		
Openings	C2.5(a)(viii)	A		V		FRL≥ -/60/-
	C2.5(b)(vi)	A		V		FRL≥ -/60/-
	C2.6(a)	A		V		
	C2.6(b)(iv)	E		V		Within the same stairway
	C2.6(b)(iv)	E		V		In external walls
	C2.7(a)(ii)	A		V		In fire walls
Patient care area	C2.5(a)(i)	A			V	Floor area ≤2000m2
	C2.5(a)(iv)(B)	A			V	Refer to C2.6
	C2.5(a)(v)	A			V	Separates from ancillary use area
	C2.10(b)	A			V	
Paint	C1.10(c)(viii)	A	V			Refer to C1.10(a)
Pedestrian ramps	C1.10(a)(vi)	A		V		Refer to specification D1.12
Plaster	C1.10(c)(i)	A	V			Refer to C1.10(a)
	C1.12(a)	A	V			Plasterboard
Proscenium curtain	C1.10(a)(v)	A	V			Refer to specification H1.3
Public corridor	C1.8(a)(ii)	S	V			
Public halls	C1.0(a)(iii)	A		V		Part H1
	C1.0(b)(iii)	A		V		Part H1
	C2.0(a)(iii)	A		V		Part H1
	C2.0(b)(iii)	A		V		Part H1
Public space	C2.4(a)(i)	A		V		
Railway station	C1.8(a)(ii)	S		V		

Object	Code	RASE	O	X	A	Information/Reference
River	C2.4(a)(i)	A		V		
Road	C2.4(a)(i)	A		V		
	C2.4(b)(i)	A		V		Public road
	C2.4(b)(iv)	A		V		Public road
Roof	C1.2(a)	S	V			Roof space
	C1.10(b)(ix)	A	V			Roof space
	C1.10(c)(ix)	S	V			Roof covering, Refer to C1.10(a)
	C1.10(c)(vii)	A	V			Roof insulating material, Refer to C1.10(a)
	C2.2(c)	S	V			Roof covering
	C2.5(a)(iv)(A)	S		V		Refer to Specification C1.1
	C2.5(a)(vii)	S	V			Roof covering, Non-combustible, refer to C2.5(a)(v)
	C2.7(b)(ii)	S		V		Underside of the roof covering
	C2.8(b)(iii)	S			V	Higher roof – lower roof ≥ 6m; Wall height – lower roof (FRL≥ fire walls)≥3m Non-combustible materials & sprinkler system refer to Specification E1.5
	Spec C1.1 Table 3	S	V			Type A
	Spec C1.1 Table 3.9	S	V			Type A Carpark
	Spec C1.1 Table 4	S	V			Type B
	Spec C1.1 Table 4.2	S	V			Type B Carpark
	Spec C1.1 Table 5	S	V			Type C
	Spec C1.1 Table 5.2	S	V			Type C Carpark
Roof light	C1.10(c)(ix)	A	V			Glass fibre reinforced polyester, Refer to C1.10(a)
Sanitary facilities	C1.7(a)	E	V			
Service structures	C2.4(a)(iv)	A		V		Such as electricity substations and pump houses

Object	Code	RASE	O	X	A	Information/Reference
Shaft	C1.8(a)(ii)	A	V			Lift shaft & Stair shaft & Service shaft
	C2.10(c)	A	V			Lift shaft FRL≥120/120/120
	C2.11	A	V			Lift shaft & Stair shaft
Sheet	C1.12(c)	A	V			Fibrous-plaster
	C1.12(d)	A	V			Fibre-reinforced cement
	C1.12(e)	A	V			Metal sheet with combustible surface & ≤1mm thickness & Spread-of-flame ≤ 0
Shelving	C1.10(c)(xii)	A	V			Refer to C1.10(a)
Skirting	C1.10(c)(iv)	A	V			Timber, Refer to C1.10(a)
Slab	C2.6(a)(iv)	A	V			
Socket-outlet	C1.10(c)(vi)	A	V			Refer to C1.10(a)
Spandrel	C2.6(a)(i)	A		V		Height≥900mm & Height ≥ 600mm above the intervening floor & FRL≥60/60/60
Sprinkler system	C1.5(b)	A	V			
	C2.1(a)	A	V			Refer to Specification E1.5
	C2.3(a)(ii)	A	V			Refer to Specification E1.5
	C2.3(b)(i)	A	V			Refer to Specification E1.5
	C2.6(b)(iii)	E	V			Refer to Specification E1.5
	C2.7(b)(iii)	A	V			Refer to Specification E1.5
Stages	C1.0(a)(iii)	A		V		Part H1
	C1.0(b)(iii)	A		V		Part H1
	C2.0(a)(iii)	A		V		Part H1
	C2.0(b)(iii)	A		V		Part H1
Storage room	C2.5(a)(vi)	A			V	Storage of medical records, Refer to C2.5(a)(v), Floor area≥10m2
	C2.5(b)(v)	A			V	Floor area≥10m2
Terrazzo	C1.10(c)(i)	A	V			Refer to C1.10(a)

Object	**Code**	**RASE**	**O**	**X**	**A**	**Information/Reference**
Tiered seating	C1.7(a)	E	V			
Theatres	C1.0(a)(iii)	A		V		Refer to Part H1
	C1.0(b)(iii)	A		V		Refer to Part H1
	C1.8(a)(ii)	A		V		Refer to Part H1
	C2.0(a)(iii)	A		V		Refer to Part H1
	C2.0(b)(iii)	A		V		Refer to Part H1
Treatment area	C2.5(a)(iii)	A			V	Floor area≤1000m2
Varnish	C1.10(c)(viii)	A	V			Refer to C1.10(a)
Vehicle access	C2.3(a)(ii)	A		V		Refer to C2.4(b)
	C2.3(b)(ii)	A				Refer to C2.4(b)
	C2.4(a)(ii)	A		V		
	C2.4(b)	A		V		
Ventilating	C1.2(b)(i)	S	V			
	C2.2(b)	S	V			
Ward area	C2.5(a)(ii)	A			V	Floor area≤1000m2
Water tanks	C1.2(b)(i)	S	V			
	C2.2(b)	S	V			
Walls	C1.2(a)	A	V			external
	C1.8(a)(ii)	A	V			external
	C1.10(a)(ii)	A	V			Wall linings, Refer to specification D1.10
	C1.10(a)(viii)	A	V			Internal walls
	C1.11	A	V			Refer to Specification C1.11
	C2.5(a)(iii)	S		V		Smoke-proof & FRL
	C2.5(a)(iv)	S	V			Fire walls
	C2.5(a)(iv)(B)	S	V			External walls
	C2.5(a)(v)	S	V			
	C2.5(a)(vii)	A	V			Refer to C2.5(a)(v)
	C2.5(b)(i)	S	V			Smoke-proof, refer to Specification C2.5
	C2.5(b)(ii)	S			V	Fire wall, FRL ≥60/60/60

Object	Code	RASE	O	X	A	Information/Reference
	C2.5(b)(iii)	S	V			Internal walls, FRL≥60/-/-, Refer to specification C1.1
	C2.5(b)(iv)	S	V			Smoke-proof, Refer to Specification C2.5
	C2.6(a)	S	V			External wall
	C2.6(a)(ii)	S	V			Curtain wall or Panel wall, Refer to C2.6(a)(i)
	C2.6(b)(v)	E	V			External walls
	C2.7(a)(i)	A			V	Fire walls, Refer to Specification C1.1 except carpark side
	C2.7(a)(ii)	A			V	Fire walls, Refer to Specification C1.1 and Part C3
	C2.7(b)(i)	A			V	Fire walls through all storeys and spaces
	C2.7(b)(iii)				V	Fire walls
	C2.8(b)	A			V	Fire walls, Refer to Table 3 or 4 or 5.
	C2.10(a)(ii)	A	V			Loadbearing, Refer to Table 4 of Specification C1.1; non-loadbearing, be of non-combustible
	Spec C1.1 Table 3	S	V			External walls (loadbearing/non-loadbearing), Common wall, Fire Wall, internal walls (loadbearing/non-loadbearing)
	Spec C1.1 Table 3.9	S	V			External walls (loadbearing/non-loadbearing), Common wall, Fire Wall, internal walls (loadbearing/non-loadbearing)
	Spec C1.1 Table 4	S	V			External walls (loadbearing/non-loadbearing), Common wall, Fire Wall, internal walls (loadbearing/non-loadbearing)
	Spec C1.1 Table 4.2	S	V			External walls (loadbearing/non-loadbearing), Common wall, Fire Wall, internal walls (loadbearing/non-loadbearing)
	Spec C1.1 Table 5	S	V			External walls (loadbearing/non-loadbearing), Common wall, Fire Wall, internal walls (loadbearing/non-loadbearing)
	Spec C1.1 Table 5.2	S	V			External walls (loadbearing/non-loadbearing), Common wall, Fire Wall, internal walls (loadbearing/non-loadbearing)
Window	C1.10(c)(iii)	A	V			Timber-framed window, Refer to C1.10(a)
	C1.10(c)(xiii)	A		V		Window treatment
	C2.5(a)(viii)	A	V			FRL≥ -/60/-
	C2.5(b)(vi)	A	V			FRL≥ -/60/-
	C2.6(a)	A	V			
Whiteboard	C1.10(c)(xiii)	A	V			

Object	Code	RASE	O	X	A	Information/Reference
Abstract Parameters						
Class of building	C1.1(b)	A		V		
	C1.3(a)	S		V		
	C1.5(b)	A		V		Class 9c
	Table C2.2	A		V		
	C2.3(a)(i)	A		V		Class 7 & 8
	C2.3(a)(ii)	A		V		Class 5-9
	C2.3(b)	A		V		Class 5-9
	C2.5	A		V		Class 9a & 9c
	C2.5(b)	A		V		Class 9c
	C2.8(b)(ii)	A		V		
	C2.9(b)	A		V		Class 2,3 or 4
	C2.10(b)	A		V		Class 9a, Class 9c
	Spec C1.1 Table 3	S		V		Type A
	Spec C1.1 Table 3.9	S		V		Type A Carpark
	Spec C1.1 Table 4	S		V		Type B
	Spec C1.1 Table 4.2	S		V		Type B Carpark
	Spec C1.1 Table 5	S		V		Type C
	Spec C1.1 Table 5.2	S		V		Type C Carpark
Fire hazard	C1.10(b)	A		V		Properties
	C2.5(a)(v)	A		V		Equipment or material
Fire-protective covering	C1.10(c)(ii)	A	V			Refer to C1.10(a)
Fire resistance level (FRL)	C1.7(a)	S	V			
	C2.5(a)(ii)(A)	S	V			Walls ≥60/60/60
	C2.5(a)(ii)(C)	S	V			Smoke-proof wall ≥60/60/60
	C2.5(a)(iv)(B)	S	V			Floors ≥120/120/120
	C2.5(a)(v)	S	V			Walls≥60/60/60
	C2.5(a)(viii)	S		V		Doorways≥-/60/30, windows≥-/60/-, other openings≥-/60/-

Object	Code	RASE	O	X	A	Information/Reference
	C2.5(b)(ii)	S	V			Fire walls & floors ≥60/60/60
	C2.5(b)(iii)	S	V			Internal walls ≥60/-/-
	C2.5(b)(vi)	S	V			Fire doors≥-/60/30, windows≥-/60/-, other openings≥-/60/-
	C2.6(a)(i)	S	V			Non-combustible material ≥60/60/60
	C2.6(a)(iv)	S	V			Non-combustible material ≥60/60/60
	C2.7(b)(iii)	S	V			Lower roof FRL ≥ fire walls
	C2.7(b)(iii)	S	V			Floor FRL ≥ fire walls
	C2.10(b)(i)	S	V			Shaft FRL≥120/120/120
	C2.10(b)(ii)	S	V			Shaft FRL≥60/60/60
	Spec 1.1 Table 3	R	V			
	Spec 1.1 Table 3.9	R	V			
	Spec 1.1 Table 4	R	V			
	Spec 1.1 Table 4.2	R	V			
	Spec 1.1 Table 5	R	V			
	Spec 1.1 Table 5.2	R	V			
Fire-retardant coatings	C1.10(b)	A	V			
Insulation materials	C1.10(a)(ix)	A	V			
Internal height	C1.2(c)	S			V	Average
Sarking-type materials	C1.10(a)(vii)	A	V			
	C1.10(a)(ix)	A	V			
Storeys	C1.1(b)	A			V	Rise in storeys
	C1.2	A			V	Rise in storeys
	C1.5	A			V	Rise in storeys
	C1.10(c)(ix)	S			V	Rise in storeys, Refer to C1.10(a)
	C1.11	S			V	Rise in storeys, Not more than 2
	C2.3(a)(i)	S			V	Rise in storeys, More than 2

Object	Code	RASE	O	X	A	Information/Reference
	C2.6(a)	S	V			
	C2.7(b)(i)	S	V			
	C2.8(a)	S	V			
	C2.9	S		V		Adjoining storeys
	C2.10(a)	S	V			
Type of construction	C1.1(b)	R		V		
	C1.3(a)	A		V		
	C1.4	A		V		
	C1.5	S		V		Type C
	C1.7(a)	S		V		Type C
	C1.10(c)(ix)	S		V		Type C, Refer to C1.10(a)
	Table C2.2	A		V		
	C2.5(a)(iv)(A)	S		V		Type A
	C2.5(a)(iv)(B)	S		V		Type B
	C2.6(a)	A		V		Type A
	C2.8(b)(ii)	S		V		
	C2.9(a)	A		V		Type A
	C2.9(b)	A		V		Type B or C
	C2.10(a)(i)	A		V		Type A, refer to Specification C1.1
	C2.10(a)(ii)	A		V		Type B
	C2.10(b)(i)	A		V		Type A, Type B
	C2.10(b)(ii)	A		V		Type C
	Spec C1.1 Table 3	A		V		Type A
	Spec C1.1 Table 3.9	A		V		Type A Carpark
	Spec C1.1 Table 4	A		V		Type B
	Spec C1.1 Table 4.2	A		V		Type B Carpark
	Spec C1.1 Table 5	A		V		Type C
	Spec C1.1 Table 5.2	A		V		Type C Carpark
Volume	C2.2(a)	A			V	
	C2.2(b)	A			V	Volume of fire compartment or atrium
	C2.2(c)	A			V	Volume of atrium

Object	Code	RASE	O	X	A	Information/Reference
	C2.3(a)	A			V	Volume≤108000m3
	C2.3(b)	A			V	Volume≥108000m3

APPENDIX 4 THE *IGNIS* TEXTUAL REPORTS

BCA COMPLIANCE ASSESSMENT REPORT

File name: Technical_school-current_school.rvt
Date/time: 18/09/2014 12:33:01pm

1. **Introduction**
   This report provides a preliminary review of the building design "Technical_school-current_school.rvt", against the deemed-to-satisfy (DTS) provisions of the Building Code of Australia (BCA) 2013 pursuant to the provisions of clause 145 of the Environmental Planning & Assessment Regulation 2000.

2. **Purpose**
   The purpose of this report is to undertake a building audit to identify the relevant DTS provisions of the BCA in relation to Section C Fire Resistance, to identify any non-compliance with the proposed development; and to identify and recommend the proposed fire safety measures for the building "Technical_school-current_school.rvt".

3. **Report Limitations**
   This report does not include nor imply all building classifications and each code of Section C Fire Resistance of BCA. The boundaries of building codes applying to this report are:

   Building classifications:
   Class 5, Class 6, Class 7a, Class 7b, Class 8, Class 9a, Class 9b, Class 9c.
   Section C:
   Part C1 – C1.1, C1.2, C1.3
   Part C2 – C2.1, C2.2, C2.5, C2.7, C2.8, C2.9, C2.10, C2.11.
   Specification C1.1.

4. **Building Classification**

Building Classification (Top Level):	Class 9b
Rise in Storeys (all):	3
Rise in Storeys (assessable):	3
Effective height:	7.6m
Type of Construction:	A

Clause	Reference	Status	Comment
Section C FIRE RESISTANCE			
Part C1 FIRE RESISTANCE AND STABILITY			
C1.1	Type of construction required	Complies	Type A construction is required. Building elements are required to achieve FRL's nominated under Table 3 of Specification C1.1.
C1.2	Calculation of rise in storeys	Complies	The building has a Rise in Storeys of 3.
C1.3	Building of Multiple classification	Complies	The Class of Building applying to the top storey Level 03-Floor is Class 9b. Type A Construction applies to all storeys.
Part C2 COMPARTMENTATION AND SEPARATION			
C2.1	Application of Part	Not Applicable	The building does not contain Open-deck Carpark that are subject to this provision.
C2.2	General Floor Area and Volume Limitations	Complies	The proposed floor area and volume of the fire compartment in the building are within the fire compartment limitations prescribed for Type A construction for the classifications concerned.
C2.5	Class 9a and 9c buildings	Not Applicable	The building does not contain class 9a and / or class 9c compartmentations.
C2.7	Separation by fire walls	Noted	The Fire wall 157807 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor. The Fire wall 157778 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor. The Fire wall 164417 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor.

Clause	Reference	Status	Comment
			The Fire wall 165237 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor. The Fire wall 165238 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor. The Fire wall 165358 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 03-Floor. The Fire wall 160284 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 02-Floor. The Fire wall 161062 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 02-Floor. The Fire wall 148960 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 01-Entry Level. The Fire wall 144180 rated --/--/-- does not reach the required FRL 120/120/120 to separate Class 5 from Class 9b in 01-Entry Level.
C2.8	Separation of classifications in the same storey	Complies	Class 5 is separated from Class 9b in Level 03-Floor; Class 5 is separated from Class 9b in Level 02-Floor; Class 6 is separated from Class 9b in Level1 01-Entry Level.
C2.9	Separation of classifications in different storeys	Complies	There are no parts of different classification which is situated one above the other in adjoining storeys.

Clause	Reference	Status	Comment
C2.9	Separation of classifications in different storeys	Complies	There are no parts of different classification which is situated one above the other in adjoining storeys.
C2.10	Separation of lift shafts	Not Applicable	This building does not contain lifts.
C2.11	Stairways and lifts in one shaft	Complies	A stairway and lift, where contains no fire wall(s) in the same shaft in Level 03-Floor, Level 02-Floor, Level 01-Entry Level,

Level	ID	Name	FRL	Required FRL
Specification C1.1				
External Walls				
03-Floor	139854	Exterior - Insulation on Masonry	30/30/30	120/60/30
	157854	Storefront	--/--/--	--/--/--
	169402	Exterior Curtain Wall	--/--/--	--/--/--
	150980	Exterior - Insulation on Masonry	30/30/30	--/--/--
	157811	Storefront	--/--/--	--/--/--
	139855	Exterior Curtain Wall	--/--/--	--/--/--
	149877	Exterior Curtain Wall	--/--/--	--/--/--
	148769	Exterior - Insulation on Masonry	30/30/30	--/--/--
	140006	Exterior Curtain Wall	--/--/--	--/--/--
	155851	Generic - 225mm Concrete	--/--/--	--/--/--
	156264	Exterior Curtain Wall	--/--/--	--/--/--
	155993	Generic - 225mm Concrete	--/--/--	--/--/--
	156281	Exterior Curtain Wall	--/--/--	--/--/--
	156072	Generic - 225mm Concrete	--/--/--	--/--/--
	156316	Exterior Curtain Wall	--/--/--	--/--/--
	156175	Generic - 225mm Concrete	--/--/--	--/--/--
	156408	Exterior Curtain Wall	--/--/--	--/--/--
	157811	Storefront	--/--/--	--/--/--
	148769	Exterior - Insulation on Masonry	30/30/30	--/--/--
	139856,	Exterior Curtain Wall	--/--/--	--/--/--
	148422	Exterior Curtain Wall	--/--/--	--/--/--
	139857	Exterior - Insulation on Masonry	30/30/30	--/--/--
	148422	Exterior Curtain Wall	--/--/--	--/--/--
	157788,	Storefront	--/--/--	--/--/--
	182328	Exterior - Insulation on Masonry	30/30/30	--/--/--
	169602	Exterior Curtain Wall	--/--/--	--/--/--
	139858	Exterior Curtain Wall	--/--/--	--/--/--
	182328	Exterior - Insulation on Masonry	30/30/30	--/--/--
	157788	Storefront	--/--/--	--/--/--
	140009	Exterior Curtain Wall	--/--/--	--/--/--
02-Floor	139854	Exterior - Insulation on Masonry	30/30/30	120/60/30
	157716	Storefront	--/--/--	--/--/--
	154279	Generic - 200mm	--/--/--	--/--/--
	169402	Exterior Curtain Wall	--/--/--	--/--/--

Level	ID	Name	FRL	Required FRL
	153616	Exterior Curtain Wall	--/--/--	--/--/--
	155419	Exterior Curtain Wall	--/--/--	--/--/--
	140003	Exterior Curtain Wall	--/--/--	--/--/--
	150980	Exterior - Insulation on Masonry	30/30/30	--/--/--
	151331	Generic - 200mm	--/--/--	--/--/--
	140006	Exterior Curtain Wall	--/--/--	--/--/--
	155851	Generic - 225mm Concrete	--/--/--	--/--/--
	156264	Exterior Curtain Wall	--/--/--	--/--/--
	155993	Generic - 225mm Concrete	--/--/--	--/--/--
	156281	Exterior Curtain Wall	--/--/--	--/--/--
	156072	Generic - 225mm Concrete	--/--/--	--/--/--
	156316	Exterior Curtain Wall	--/--/--	--/--/--
	156175	Generic - 225mm Concrete	--/--/--	--/--/--
	162023	Storefront	--/--/--	--/--/--
	150861	Generic - 200mm	--/--/--	--/--/--
	157673	Storefront	--/--/--	--/--/--
	139855	Exterior Curtain Wall	--/--/--	--/--/--
	149877	Exterior Curtain Wall	--/--/--	--/--/--
	148769	Exterior - Insulation on Masonry	30/30/30	--/--/--
	139856	Exterior Curtain Wall	--/--/--	--/--/--
	157669	Storefront	--/--/--	--/--/--
	162524	Storefront	--/--/--	--/--/--
	148422	Exterior Curtain Wall	--/--/--	--/--/--
	139857	Exterior - Insulation on Masonry	30/30/30	--/--/--
	144344	Generic - 200mm	--/--/--	--/--/--
	157650	Storefront	--/--/--	--/--/--
	182328	Exterior - Insulation on Masonry	30/30/30	--/--/--
	169602	Exterior Curtain Wall	--/--/--	--/--/--
	139858	Exterior Curtain Wall	--/--/--	--/--/--
	156408	Exterior Curtain Wall	--/--/--	--/--/--
	140009	Exterior Curtain Wall	--/--/--	--/--/--
01-Entry Level	144837	Exterior - Insulation on Masonry	30/30/30	--/--/--
	196713	Exterior Curtain Wall	--/--/--	--/--/--
	169770	Exterior - Insulation on Masonry	30/30/30	--/--/--
	145547	Exterior Curtain Wall	--/--/--	--/--/--
	140006	Exterior Curtain Wall	--/--/--	--/--/--

Level	ID	Name	FRL	Required FRL
	155851	Generic - 225mm Concrete	--/--/--	--/--/--
	156264	Exterior Curtain Wall	--/--/--	--/--/--
	155993	Generic - 225mm Concrete	--/--/--	--/--/--
	156281	Exterior Curtain Wall	--/--/--	--/--/--
	156072	Generic - 225mm Concrete	--/--/--	--/--/--
	156316	Exterior Curtain Wall	--/--/--	--/--/--
	156175	Generic - 225mm Concrete	--/--/--	--/--/--
	156408	Exterior Curtain Wall	--/--/--	--/--/--
	148960	Storefront	--/--/--	--/--/--
	150861	Generic - 200mm	--/--/--	--/--/--
	151588	Storefront	--/--/--	--/--/--
	151331	Generic - 200mm	--/--/--	--/--/--
	139856	Exterior Curtain Wall	--/--/--	--/--/--
	139857	Exterior - Insulation on Masonry	30/30/30	--/--/--
	148422	Exterior Curtain Wall	--/--/--	--/--/--
	144344	Generic - 200mm	--/--/--	--/--/--
	147833	Storefront	--/--/--	--/--/--
	182328	Exterior - Insulation on Masonry	30/30/30	--/--/--
	139858	Exterior Curtain Wall	--/--/--	--/--/--
	140009	Exterior Curtain Wall	--/--/--	--/--/--
	148769	Exterior - Insulation on Masonry	30/30/30	--/--/--
	149877	Exterior Curtain Wall	--/--/--	--/--/--
	140012	Pavillion Curtain Wall	--/--/--	--/--/--
	140018	Pavillion Curtain Wall	--/--/--	--/--/--
	140015	Pavillion Curtain Wall	--/--/--	--/--/--
	139855	Exterior Curtain Wall	--/--/--	--/--/--
	150980	Exterior - Insulation on Masonry	--/--/--	--/--/--
	139854	Exterior - Insulation on Masonry	30/30/30	120/60/30
	155419	Exterior Curtain Wall	--/--/--	--/--/--
	140003	Exterior Curtain Wall	--/--/--	--/--/--
	154279	Generic - 200mm	--/--/--	--/--/--
	155159	Storefront	--/--/--	--/--/--
	153616	Exterior Curtain Wall	--/--/--	--/--/--
	154427	Exterior - Insulation on Masonry	--/--/--	--/--/--

APPENDIX 5 DEMONSTRATION DOCUMENT FOR EVALUATIONS

Design concepts for a code-checking system using Building Information Modelling (BIM)

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Content

- Background
- Aims and Purposes
- BIM technology
- Research Scope and limitations
- Structure of the target building codes

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Background

- Construction industry incorporates technologies such as building information modelling (BIM) to enhance productivities, qualities and collaboration for building designs.
- No technologies can help assess building design models for compliance with building regulations during the design process.
- No technologies can provide consistent assistances for accredited certifiers to improve the efficiency and consistency of certifying activities.

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Aims and Purposes

- **Aims**

  Develop a BIM-CCS to **assist designers identifying non-compliances of building designs during the design process**.

- **Purposes**

  Assess the efficacy of the BIM-CCS by certifiers accredited by Building Professional Board (BPB).

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Isn't BIM just 3D CAD

- Short answer: **no**.

- 3D CAD is a graphical representation of the building.
  - Points, lines, arcs and faces.

- BIM 3D Models are in effect a database of parametric objects
  - Properties, both physical and functional

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What is BIM

- BIM is an approach to the **whole project life cycle**.

- Allows us to **coordinate, update and share** design information with various team members throughout the **design, construction and management** phases of the building's life.

- BIM is NOT a single software or process. It is more about synergy between technology, policy and process.

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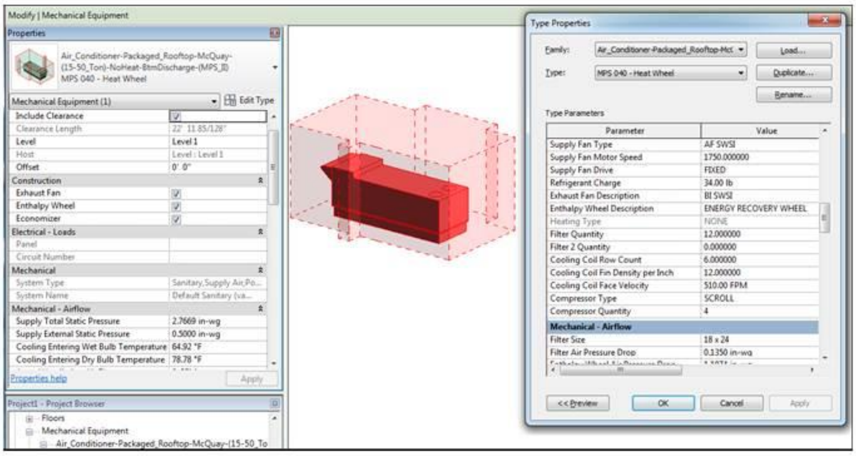
BIM – Parameters



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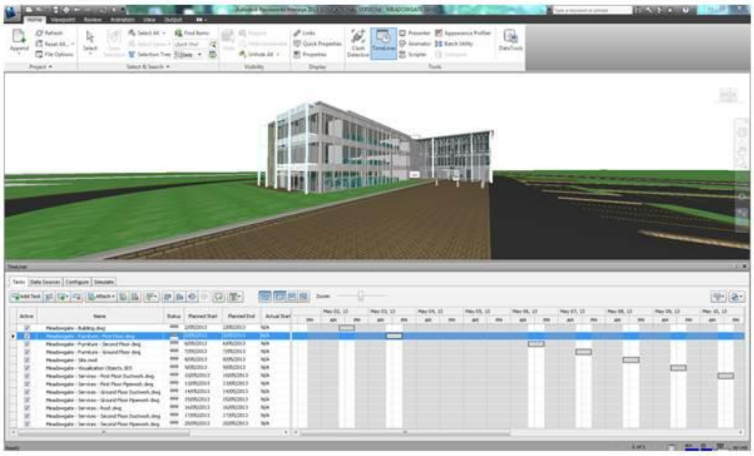
BIM - Scheduling



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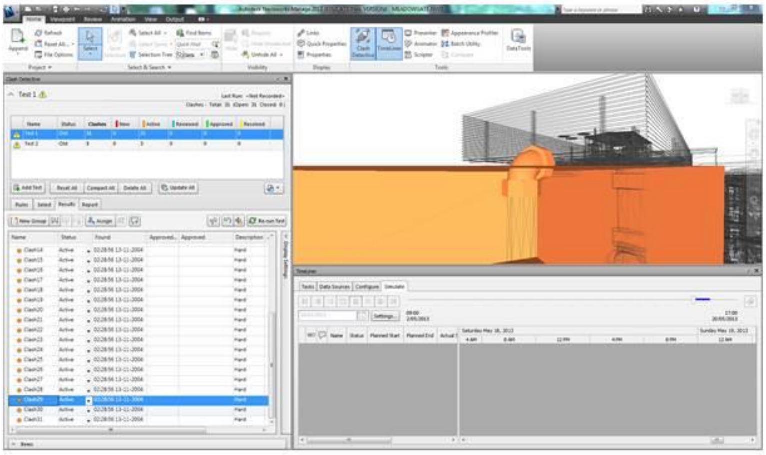
BIM – Clash detection



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Scope of BIM-CCS

- Regulations:
  - Commercial Buildings (Class 5 – 9).
  - Section C Fire Resistance, BCA (Deem-to-satisfied regulations).

- Models: BIM models (provided by Autodesk Revit).

- Platforms: Built-in system on Autodesk Revit 2014.

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Target Building Classes

- Class 5 – Office Type Building
- Class 6 – Shop Type Building
- Class 7
  - Class 7a - Carpark
  - Class 7b - Warehouse for Storage or Display
- Class 8 – Laboratory or Building used for Production
- Class 9
  - Class 9a - Health Care Building
  - Class 9b - A public assembly building
  - Class 9c - Aged Care Building

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Target Building Codes

- Part C1 Fire resistance and stability
  - C1.1 Type of construction required
  - C1.2 Calculation of rise in storeys
  - C1.3 Building of Multiple classification
- Part C2 Compartmentation and separation
  - C2.1 Application of Part
  - C2.2 General Floor Area and Volume Limitations
  - C2.5 Class 9a and 9c buildings
  - C2.7 Separation by fire walls
  - C2.8 Separation of classifications in the same storey
  - C2.9 Separation of classifications in different storeys
  - C2.10 Separation of lift shafts
  - C2.11 Stairways and lifts in one shaft
- Specification C1.1 Fire-resisting construction

  (Table 3/3.9/4/4.2/5/5.2)
  - External walls
  - Internal walls
  - Fire walls
  - Columns
  - Floors
  - Roofs

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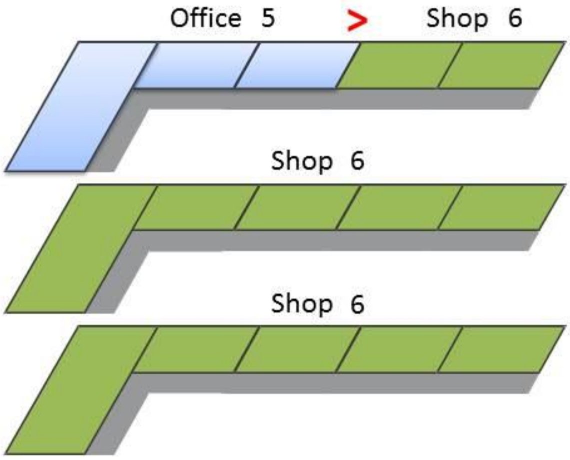
C1.1 Type of construction required

back



- Rise in Storeys (C1.2) and,
- Building class for the top storey (C1.3).

Table C1.1 Type pf Construction		
Rise in storeys	Class of building	
	2,3,9	5,6,7,8
4 or more	A	A
3	A	**B**
2	B	C
1	C	C

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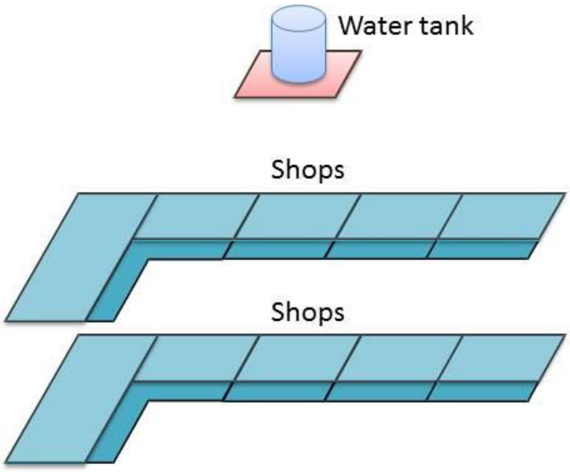
C1.2 Calculation of rise in storeys

back



- Service Units on top floor.
  - Put objects only.
  - Do not add room tags.

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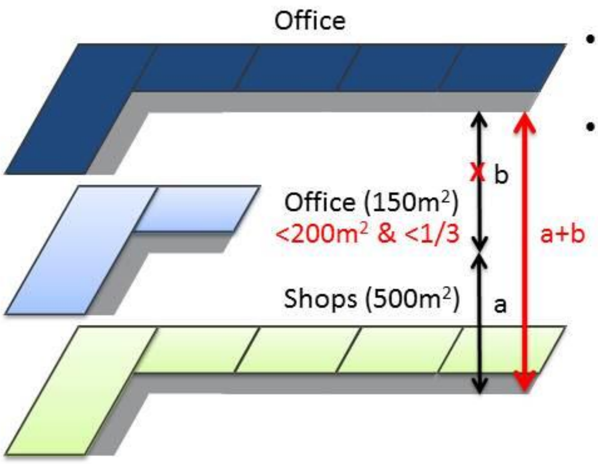
C1.2 Calculation of rise in storeys



- No parameters showing mezzanine levels.
- Mezzanines is seen as a storey.
  - Floor areas>200m², or
  - Floor areas<200m² and >1/3 of its next level.

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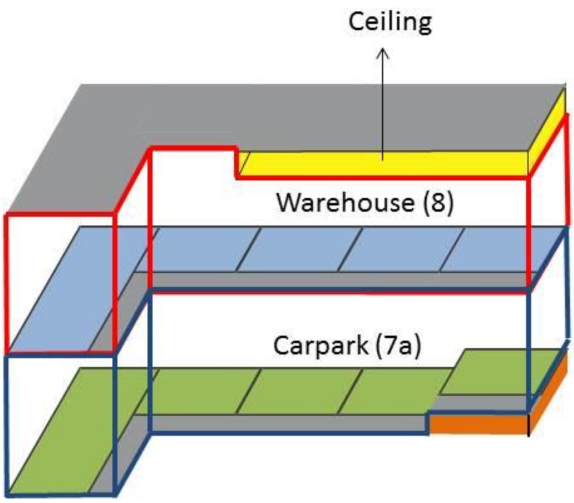
C1.2 Calculation of rise in storeys

back



- Average internal height in a Class 7 or 8 buildings.
  - Find the main building class
  - Calculate average internal height (volume/floors)

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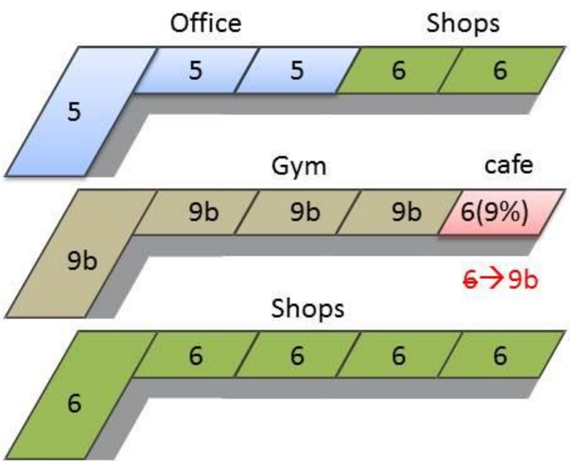
C1.3 Building of Multiple classification

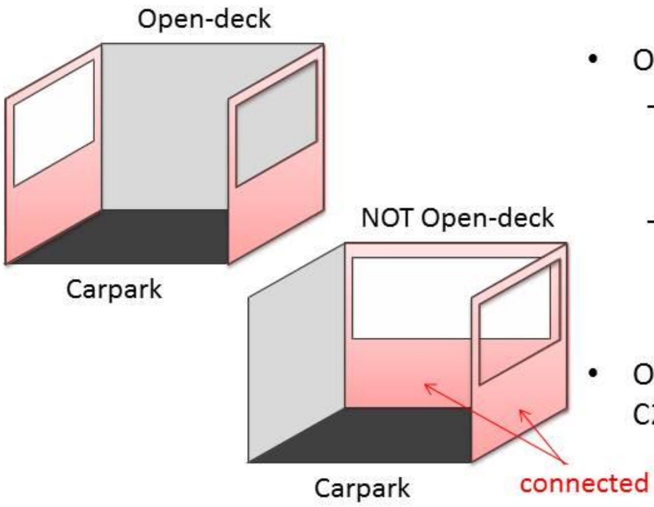
back



- Setting building classes
  - room tag table
- Calculating floor areas for each building class
  - The largest
  - Less than 10% of all

C2.1 Application of Part

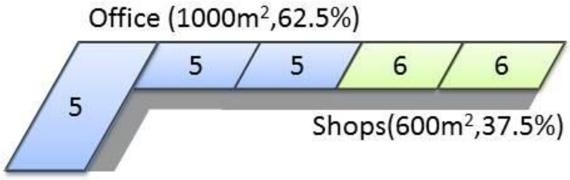
back



- Open-deck carpark
  - Enclosed by 5 or more walls, 3 or more external walls have opening area over ½.
  - Enclosed by 4 or more walls, 2 external walls have opening areas over ½ and they are not connected.
- Open-deck carpark is not used for C2.2.

C2.2 General Floor Area and Volume Limitations

back



- Calculating floor areas for building classes by each level.
- Comparing to the requirements of Table C2.2.

Type C construction

- Office: 3000(max)X62.5%=1875
- Shops: 2000(max)X37.5%=750

Table C2.2 Maximum size of fire compartments or atria

Classification		Type of construction of building		
		Type A	Type B	Type C
5, 9b or 9c aged care building	Max floor area -	8 000 m²	5 500 m²	3 000 m²
	Max volume -	48 000 m³	33 000 m³	18 000 m³
6, 7, 8 or 9a (except for patient care areas)	Max floor area -	5 000 m²	3 500 m²	2 000 m²
	Max volume -	30 000 m³	21 000 m³	12 000 m³

Note: See C2.5 for maximum size of compartments in patient care areas in Class 9a health care buildings

- Class 5: 1875>1000→satisfied
- Class 6: 750>600→satisfied
- Total area: 1875+750=2625 > 1000+600=1600→satisfied

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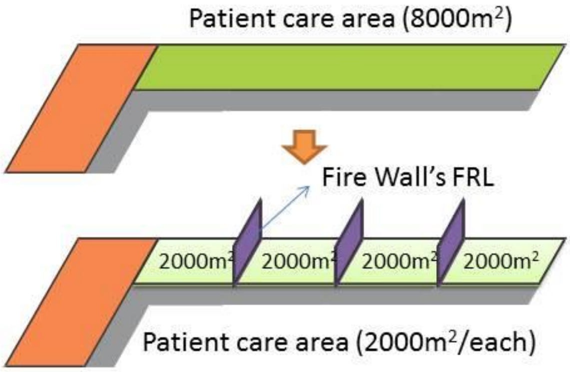
C2.5 Class 9a and 9c buildings

back



- Building class in 9a or 9c.
- Calculating floor areas for each area (room tags).
- limitations:
  - Patient care (2000m²),
  - Ward (1000m²),
  - Treatment (1000m²),
  - Kitchen (30m²),
  - Storage (10m²).

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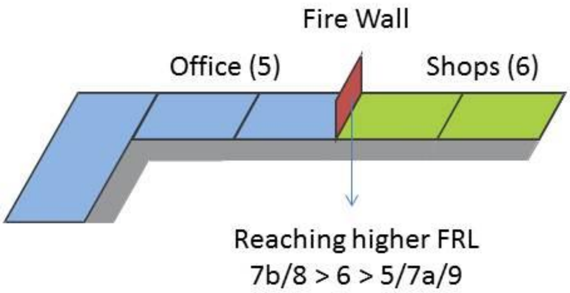
C2.7 Separation by fire walls

back



- Separation of fire compartments.
- Building classes within a level.
- Exploring fire rating of the fire wall that separates building classes.
- Exploring fire walls extending to the roof or its upper level's floor.
  - The FRL of upper level's floor is not provided.

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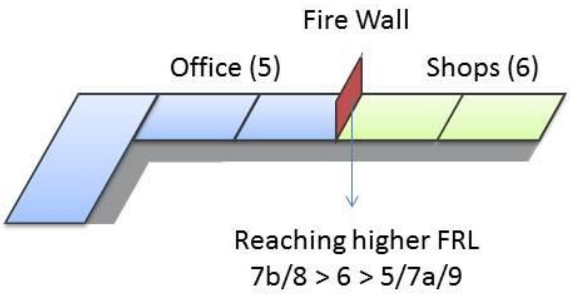
C2.8 Separation of classifications in the same storey

back



- Building classes within a level.
- Exploring fire rating of the fire wall that separates building classes.

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C2.9 Separation of classifications in different storeys

back

- The fire rating of floors cannot be assessed.
- Suggested references are proposed in the report.

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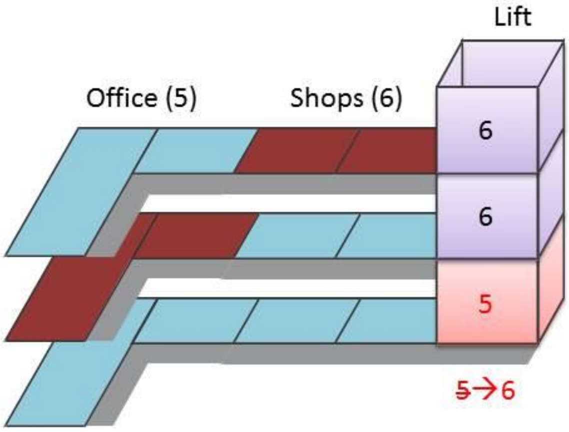
C2.10 Separation of lift shafts

back



- Exploring lift objects or room tag
- Checking the enclosed wall's FRL.

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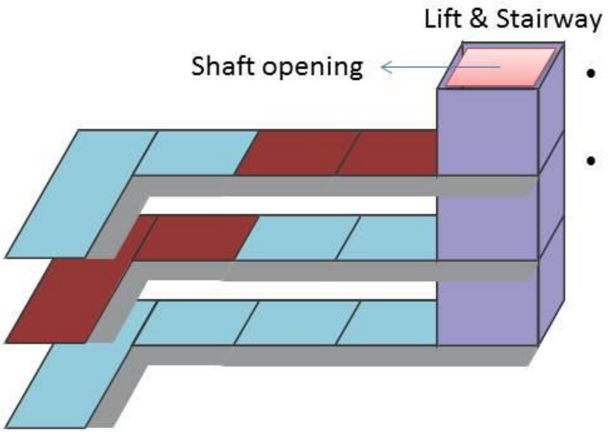
C2.11 Stairways and lifts in one shaft

back



- Exploring stairways and lifts objects separately.
- Exploring if their positions situated in the same shaft opening.

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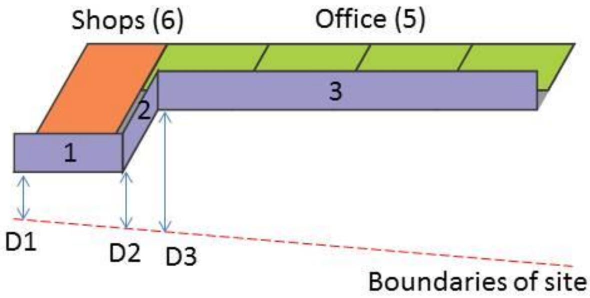
External walls

back



- Wall function (External)
- Distance to fire source features
  - Boundaries of site
- Wall structure (loadbearing or non-loadbearing)

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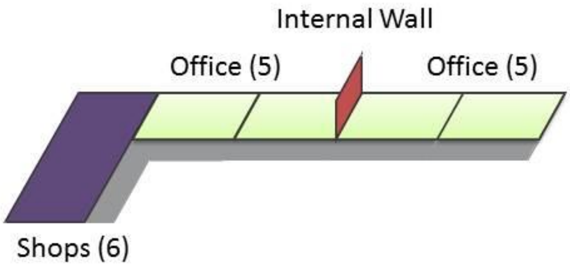
Internal walls

back



- Wall function (Internal)
- Building classes (Room tags)
- Wall structure (loadbearing or non-loadbearing)

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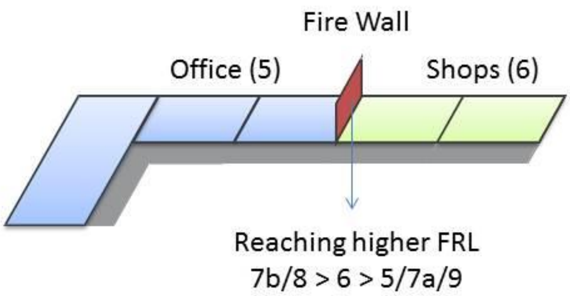
Fire walls

back



- Building classes (Room tags)
- Wall function (fire wall)

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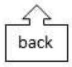
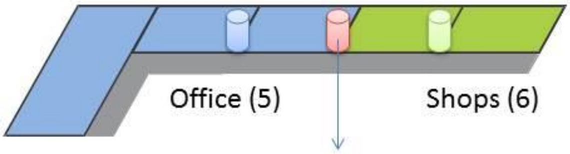
Columns



- No fire rating parameters
- According to the building class of each room.



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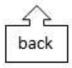
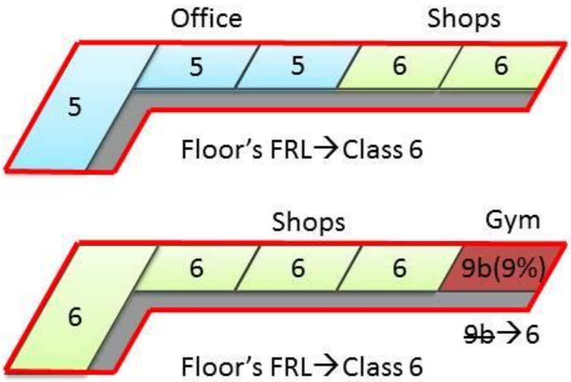
Floors





- No fire rating parameters
- Providing FRL suggestions on report.
- According to the building class having higher FRL requirements.

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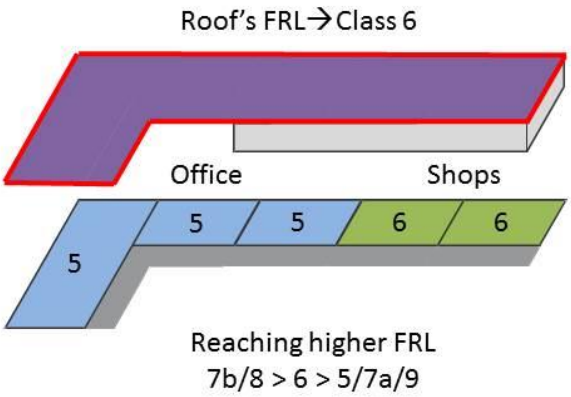
Roofs

back



- No fire rating parameters
- Providing FRL suggestions on report.
- According to the building class having higher FRL requirements.

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