Roadmap to Mature BIM Use in Australian SMEs: A Competitive Dynamics Perspective

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Abstract

This research explores and reports upon the scale of BIM implementation maturity (from non-adoption to full-scale deployment) within Small-to-Medium Enterprises (SMEs) operating within the Australian construction industry. The research utilizes a Competitive Dynamics Perspective (CDP) as the theoretical lens and analyses data collected from 135 SMEs using Bayesian Belief Networks (BBNs) to provide a richer insight into levels of BIM implementation maturity. Findings reveal that there is no meaningful association between BIM implementation maturity within SMEs and their organizational attributes (such as size and level of experience). Additionally, lack of solid evidence to support a reasonable return on investment (ROI) was found to be the key barrier to using BIM in higher levels of maturity. In practical terms, the study focuses upon pertinent issues associated with mandated BIM in Australia from SMEs' perspective, pointing out potential consequences, and challenging the pressure for mandating. The research concludes by providing pragmatic recommendations designed to accelerate the pace that Australian SMEs move across a BIM trajectory from non-adopters to higher levels of maturity.

Keywords: Building information modeling (BIM), SMEs, adoption, implementation, antecedents, barriers, construction industry, Australia

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Introduction

Winch (1998) defined 'adoption' within a construction context, as a final stage in a decision making process that culminates in resolution to adopt and use a new system, process or idea. Within contemporary practice, Building Information Modelling (BIM) is a relatively new disruptive technology whose adoption (and subsequent implementation) has been largely inconsistent – both across developed and developing countries, and amongst various sizes and types of construction firm (Davies and Harty 2013). The term 'BIM use' captures the status of BIM execution on construction projects, covering an entire range, from partial adoption to full-scale implementation (Mayo et al. 2012). However, many construction firms have not adopted this technology (Cao et al. 2017) and consequently, BIM implementation resides in its infancy (Manderson et al. 2015). Evidence illustrates that Small-to-Medium Enterprises (SMEs) in particular are slow to adopt full-scale BIM implementation (analogous to the UK's level 1 maturity) when compared to large-sized construction companies (Hosseini et al. 2016; Lam et al. 2017). Almost 75% of SME-contracting firms are among non-adopters and only around 5% have accrued experience of the UK's BIM Level 3 criteria (Dainty et al. 2017). Nevertheless, embedding widespread and mature use of BIM is essential to an industry that is heavily reliant upon engaging SMEs (Hosseini et al. 2016). As asserted by Shelton et al. (2016):

> *"...smaller firms will continue to dominate the construction industry landscape far into the future."*

Such realization has stimulated increasing interest amongst practitioners and academics who have sought to discover the level of BIM adoption and implementation amongst SMEs and moreover, identify the barriers and enablers to such (Lam et al. 2017). Therefore, promoting both BIM adoption and implementation in SMEs is an important mediator for BIM proliferation throughout the construction industry (Dainty et al. 2017).

Within recent extant literature a significant paradigm shift in research focus on BIM use has occurred; specifically, from total concentration on adoption and non-adopters towards investigating BIM use in levels 2 and 3 (Chong et al. 2017). However, the academic discourse reveals that pertinent research is largely monothematic, almost entirely focused on models, frameworks and lists of barriers to address the problem of BIM adoption in SMEs (Hosseini et al. 2016; Lam et al. 2017). For example, Hosseini et al. (2016) presented a model of barriers whilst Lam et al. (2017) proposed a decision making system to support SMEs to make appropriate decisions on BIM adoption. To date, augmenting SMEs' decision making and investigations into BIM adoption have predominated. However, implementation of BIM in SMEs post adoption has received scant attention (Hosseini et al. 2016). This study addresses this fundamental knowledge gap by providing insights into the issues surrounding SMEs implementing BIM in levels 2 and 3. In so doing, the study identifies the relationship between SMEs attributes and BIM use, and defines the main barriers to higher levels of BIM use.

SMEs in Construction

SMEs broadly fall within three categories, namely micro, small and medium-sized enterprises, and are defined as having ≤ 4 employees, 5 and 20 and 20 – 200 employees respectively (SMEAA 2011). SMEs represent around 98% of the construction sector in countries such as Australia, the US, the UK and Canada; where up to 70% of this total are micro businesses (Forsythe 2014; Killip 2013; Poirier et al. 2015). Likewise, in the European Union (EU), around 99% of firms within the Architectural, Engineering, Construction and Owner-operated (AECO) sector (Papadonikolaki et al.) are SMEs, where 95% are micro-enterprises (Ueapme 2017). Therefore, studying BIM use within SMEs has global significance and impact reach (Dainty et al. 2017) because they are the cornerstone of a nation's economy's prosperity and dominate the construction market on a global scale (Shelton et al. 2016; SMEAA 2011; Killip 2013). Compared against their larger counterparts, SMEs are typically: nimbler in terms of their structure; are more agile and can move faster to exploit new business opportunities in the market (Rosenbusch et al. 2011). Yet despite these palpable benefits, SMEs struggle to maintain their competitive edge due to the lack of sufficient resources and key assets (Saridakis et al. 2013). Academic scholars assert that SMEs typically lag behind large-sized firms in embracing innovative technological advancements (such as BIM) and are thus unable to reap concomitant performance enhancements (Bröchner and Lagerqvist 2016; Forsythe 2014; Lam et al. 2017; McGraw-Hill 2014; Poirier et al. 2015; Shelton et al. 2016).

BIM Use

Whilst BIM represents a technological innovation, the processes of applying BIM in construction organizations can be conceptualized through the lens of innovation diffusion theory (c.f. Cao et al. 2017; Gledson 2016; Poirier et al. 2015). Consequently, the first engagement of companies with BIM involves making a decision on either using BIM or persevering with traditional methods – a process often based upon: market pressure (Lee et al. 2015); clients' demands (Elmualim and Gilder 2014; Papadonikolaki and Wamelink 2017); and bandwagon impacts, namely, pressures stemming from awareness of the sheer number of firms that have already adopted BIM (Kale and Arditi 2010). An introspective evaluation of company capabilities in providing essential resources is similarly influential (Cao et al. 2017; Kale and Arditi 2010; Lee et al. 2015). In BIM terminology, companies that shy away from BIM adoption remain in 'pre-BIM' status where project information is largely stored on paper (Khosrowshahi and Arayici 2012).

For firms opting into BIM adoption, the next steps require an incremental and sustained shift to BIM implementation; a process defined by several maturity stages (Succar 2009). BIM maturity models are based on 'stages theory', representing a step-by-step evolution of a process according to well-defined milestones (Liang et al. 2016). There are various systems for defining maturity levels in BIM use (Mayo et al. 2012), each with unique areas of emphasis, strengths, weaknesses and/ or specifically designed for a certain group of BIM users (Liang et al. 2016; Wu et al. 2017) – yet, curiously there is no universally accepted system (Wu et al. 2017). According to Succar's (2009) seminal study, BIM implementation can occur in three consecutive evolutionary stages, namely: *stage 1* - object-based modelling; *stage 2* - model-based modeling; and *stage 3* – materialization of network-oriented integration. Papadonikolaki et al. (2016) classified BIM implementation process into *ad-hoc*, linear or distributed depending on the extent of digital and organizational functionalities used across the supply chain. From another perspective, the National Building Specification (NBS 2014) classified BIM implementation within firms into four different levels, namely: *level 0* - unmanaged CAD in 2D documentations with paper or electronic data exchange; *level 1*- CAD in 2D or 3D formats to present design through a collaborative tool and a common data environment (CDE); *level 2* - 3D formats through an individual BIM platform and software tools are utilized, with data attached including 4D (time) and/or 5D (cost) data; and *level 3* - a fully integrated and collaborative real-time project model facilitated by web services. These levels along with the pre-BIM status provide a straightforward benchmark for assessing the maturity of BIM engagement within construction companies (c.f. Khosrowshahi and Arayici (2012). Consequently, this 4 level system (0-3) was adopted for this research, given its wider acceptance in the field and flexible operational considerations (c.f. Liang et al. (2016).

Factors Associated with BIM Use

Various factors are associated with a firm's willingness, motivations and capacity to adopt BIM but prominent demographics include: company size, clientele, history/experience of the firms (Cao et al. 2017; Lee et al. 2015), along with their role in the construction supply chain (Ashcraft 2008; McGraw-Hill 2014).

Role

BIM use across the construction supply chain is typically demanded by those playing the client or owner role *ad interim* (Papadonikolaki et al. 2017), given that BIM use increases their involvement in delivering projects (Love et al. 2015). BIM use amongst individuals within a project management team (architects, owners, contractors etc.) varies as each party is confronted with disparate challenges that are unique to that role (Ashcraft 2008; Papadonikolaki et al. 2017; Dossick and Neff 2010). Consequently, various roles across the construction supply chain show different levels of interest towards BIM (McGraw-Hill 2014).

Company Size

Eadie et al. (2013) proffered that company size is an important determinant of BIM use while Jaradat and Sexton (2016) and Hosseini et al. (2016) claimed that construction management research conducted has favoured BIM adoption in large practices and megaprojects – such work has inadvertently created the impression that BIM is for large organizations. In support of this largely unsubstantiated conjecture, Dainty et al. (2017) stated that BIM uptake is:

> *"likely to be more problematic for smaller firms without the resources and capacity to invest in the technology*."

Dainty's research (*ibid.*) implies that a cavernous *'digital divide'* has transpired between SMEs, large firms and their respective BIM adoption level - caused by insufficient resources, finance and/ or knowledge or skills inherent within the workforce (Eadie et al. 2013). Large firms are eager to adopt BIM because it is considered as strategically important to drive business growth (Acar et al. 2005; Shelton et al. 2016; Barata and Fontainha 2017). However, Acar et al. (2005) found that the business characteristics of construction SMEs are heterogeneous and therefore size is not the only characteristic that influences BIM use.

Clientele

As BIM increasingly gains popularity, numerous construction clients are desirous to explore and profit from BIM's acclaimed benefits accrued during the production and operation of a building or infrastructure asset (Pärn *et al.*, 2017). This growth has been fortified by industry reports that claim that most owners in the US (69%) and UK (80%) are positive in their overall assessment of BIM (McGraw-Hill 2014). However, UK clients feel that the UK Government's BIM mandates are:

> *"forcing them to adopt BIM, regardless of their own interest in doing so."* (McGraw-Hill 2014)

This highlights an important interdependence between clients and governmental regulation, which might be a driver for increasing BIM use across countries in the future (Porwal and Hewage 2013). However, in countries where BIM is not mandated for public projects (such as Australia), other actors (such as leading and innovative contractors and consultants) might be equally dominant and influential in driving the agenda (Hosseini et al. 2016; Papadonikolaki et al. 2017). Another prominent factor underpinning BIM adoption is a firm's clientele which is related to its history and experience (Eadie et al. 2013).

History/ Experience

A firm's history and project portfolio (i.e. what balance of public vis-a-vis private projects are undertaken), can determine their motivation and urgency to use BIM in projects (Eadie et al. 2013; Lee and Yu 2016). According to Arayici et al. (2011), a firm's past experience of BIM and '*forward thinking top management'* who are be supportive of this process are decisive ingredients for the successful adoption and implement of BIM. A firm's history and experience also has great affinity to any long-term relations or repetitive projects. For example, long-term partnerships in the Netherlands (where alliancing is popular) tend to regulate each other by jointly deciding to use BIM in their projects (Papadonikolaki and Wamelink 2017). This is related to meso-level mimetic mechanisms that constitute a contributing factor to macro-BIM adoption (Succar and Kassem 2015). When SMEs partner with larger and established firms they gain access to a greater market share, clientele and resources (Manley 2008). Barata and Fontainha (2017) support this assertion and state that '*internationalization contributes to innovation*' and that firms experienced in the international market tend to be more innovative than firms at a national, regional or local level.

Barriers to Mature Use of BIM in SMEs

Various factors can hinder BIM use (Eadie et al. 2013; Lee and Yu 2016) albeit, there is a dearth of research from an SME's perspective (Dainty et al. 2017; Hosseini et al. 2016). Barriers identified can be categorized into three thematic categories, namely: i) demand for, and inter-organizational capabilities to supply BIM work; ii) intra-organizational resources; and iii) firms' perceived benefits of BIM implementation (Lee and Yu 2016), as tabulated in Table 1.

<INSERT TABLE 1 HERE>

Demand and Supply

Several scholars have reported upon a lack of client demand for investing and using BIM (Aibinu and Venkatesh 2014; Goucher and Thurairajah 2012). In addition, Won et al. (2013), suggests that not all projects are appropriate for BIM use for example, small projects can be too simplistic realize the maximum benefits of BIM. Firms may struggle to align BIM implementation with the inter-organizational capabilities supplied by their counterparts and partners (Papadonikolaki et al. 2016; Papadonikolaki and Wamelink 2017).

Intra-organizational Resources

At an intra-organizational level, limited resources within SMEs influence their ability to use BIM in projects (Eadie et al. 2013). Financial barriers of BIM are pervasive and include software and licenses procurement and hardware upgrades that proportionally, represent a far greater burden for SMEs (Aibinu and Venkatesh 2014; Ganah and John 2014; McGraw-Hill 2012; Stanley and Thurnell 2014; Yan and Demian 2008). In addition to the cost of investing in BIM infrastructure, the time and cost required to train staff are the largest barriers to BIM adoption and are particularly influential on SMEs (Yan and Demian 2008; Aibinu and Venkatesh 2014; Becerik-Gerber B. 2011; Eadie et al. 2013). Even when knowledgeable people are trained, found and employed, their existing skills-set must be continually upgraded via continuous professional development to keep them abreast of the latest advancements. Managing change and ensuring trust among the team represent further considerations amongst firms striving to transform their business to embrace BIM adoption (Aibinu and Venkatesh 2014; Cao et al. 2014; Papadonikolaki et al. 2017; Papadonikolaki et al. 2016; Won et al. 2013). Indeed, Azhar (2011) purports that the barriers to BIM use are either technical or managerial, whilst Hosseini et al. (2016) and Won et al. (2013) proffer that managing the non-technical organizational issues was more urgent than technical barriers.

Perceived Benefits

Firms may display a lack of motivation to use BIM when the technology: *"is perceived to be flawed in terms of user-friendliness, usefulness, attractiveness and affordability"* (Dainty et al. 2017). Prominent and omnipresent issues such as the lack of interoperability between different platforms and proprietary files is a notable barrier to utilizing BIM to its full potential (Aibinu and Venkatesh 2014; Demian and Walters 2014; Grilo and Jardim-Goncalves 2010; Stanley and Thurnell 2014). Similarly, Arayici et al. (2011) reported upon the struggles associated with having a common language for data exchange in a BIM environment. Yan and Demian (2008) also discovered that a significant percentage of organizations believed that BIM is unsuitable for their current projects and that existing technologies were sufficient for delivering their services. Thus, the above effectuate lack of senior management buy-in towards BIM adoption (McGraw-Hill 2012).

Theoretical Lens of Competitive Dynamics Perspective

While BIM is a disruptive technological innovation (Cao et al. 2014; Poirier et al. 2015), the term 'BIM use' refers to both BIM adoption and implementation in understanding BIM execution features (Mayo et al. 2012). Hence, studying the behaviors of SMEs towards BIM use must consider all influential external and internal motivators acting upon a firm (Murphy 2014). Evidence illustrates that the perceptions of key decision makers in SMEs (regarding BIM's potential to enhance performance and strengthen market position) are pivotal to BIM adoption (Dainty et al. 2017; Hosseini et al. 2016). Specifically, return on investment and a robust financial assessment of the essential resources required are the most influential factors shaping these perceptions and consequently, the behavior of SMEs towards BIM adoption (McGraw-Hill 2014; Poirier et al. 2015). With the aforementioned in mind, this research draws upon a Competitive Dynamics Perspective (CDP) (Ketchen et al. 2004), as the theoretical lens to explain and interpret the observed behaviors of SMEs towards BIM use. The foundation of CDP is grounded in providing insights into the interactions of organizations that embrace new products, and explaining managers' behaviors in attempting to maximize firms' profit and performance (Ketchen et al. 2004). CDP is an effective explanatory tool for linking strategic decisions, actions and processes, resource-oriented considerations, and market perspectives on innovations and new products (Chen and Miller 2012). This theoretical lens has the inherent ability to explain the behavior of organizations towards the market and profit effects of innovative actions (Smith et al. 2001). These features make CDP an effective approach to explaining the behavior of SMEs towards BIM use.

Research Approach

Behavior of construction practitioners (including those working for SMEs) towards any innovation is shaped by their assumptions and perceptions of it (Shelton et al. 2016); investigating perceptions as subjective phenomena, necessitates building awareness of the behavior of individuals. To elicit knowledge from practitioners in SMEs (the target population), quantitative data collection was deemed a suitable method, given its capability to generalize findings (Mackenzie and Knipe 2006). A questionnaire survey is a ubiquitous quantitative data collection instrument, designed to: elicit knowledge; give meaning to the aggregated behavior of a group of individuals; and discern existing patterns of association (Robson 2002). With the aforementioned in mind, a survey questionnaire among Australian SMEs was selected and further description is herein further elucidated upon.

Rationale and data collection

The questionnaire utilized was based upon the questionnaire deployed to measure the adoption of BIM by South Australian SMEs (c.f. Hosseini et al. (2016). This pre-existing questionnaire was extensively tested at the time of use and proved to be a robust, valid and reliable data collection instrument. The questionnaire was revised to incorporate the concept and levels of BIM implementation. Within the questionnaire's preliminary section, key terms such as BIM and levels of BIM implementation were explained and defined using professional expressions rather than academic terms. A description of the research project's aims was also given and some rudimentary questions were presented to identify the respondents' demographic profile. The questionnaire's second section included statements describing the barriers, which make construction practitioners in SMEs shy away from moving to higher levels of BIM implementation. Respondents were asked to rate their level of agreement with regard to the influence of the described barriers via a five-point Likert-item rating where (1 = *strongly disagree,* 2 = *disagree,* 3 = *neutral,* 4 = *agree, and 5 = strongly agree*).

Sampling process

Australian construction related firms from various disciplines (such as contractors, architecture and design companies) were identified as the target population. Cluster sampling by profession (Neuman 2006) was then adopted as an administrative technique deployed to collate a representative sample within Australia's wide geographic area. Lists of architects, design firms and contractors were collated arbitrarily from publicly available databases, such as websites and the Yellow Pages. A total of 1,365 (712 architects/ design firms and 653 contractors) questionnaires were distributed by post to company headquarters and follow-on emails posted to directors of these companies. A total of 149 completed questionnaires were returned, demonstrating a response rate of 11% - such was previously deemed acceptable within contemporary construction management research (Bing et al. 2005). The data collection commenced October 2015 and was finalized in February 2016. Of these questionnaires, 135 fell within the category of SMEs and the rest 14 completed questionnaires were from large-sized companies and hence, were omitted from further analysis. Therefore, these residual 135 questionnaires formed the basis for data analyses.

Table 2 reports upon the demographic profile of Australian SMEs represented in the dataset of the study. Regards size of firm, 126 out of 135 (~ 93%) were micro and small businesses while medium sized companies constituted the remaining ~ 7% of sample SMEs. 128 of participants (~ 95%) were working with owners/ individuals or private organizations, exposing their predominant reliance upon the private sector and *de facto* exclusion from government contracts. Close to 39% of respondents represented contractor/ builder companies, whereas design companies made up ~ 61% of the sample.

<INSERT TABLE 2 HERE>

Sample demographics provided evidence of the adequacy of respondent knowledge completing the survey. That is, 124 out of 135, namely ~ 92% of participants were from companies with > 11 years of experience within the construction industry, denoting their involvement and awareness of developments occurring in the industry and awareness of a shift from traditional methods of project management towards BIM. Further, 119 (~ 88%) of respondents were directors and project managers of companies (refer to Table 2) and essentially key decision makers within their organizations. Thus, survey respondents were immersed in decision making processes and related procedures, thus denoting their first-hand involvement and awareness of company policies and strategies with regard to BIM.

Data Analysis Using Bayesian Belief Networks

Bayesian Belief Networks (BBNs) are efficient tools to facilitate accurate reasoning when limited data are available from a real-life complex environment (Ben et al. 2007; Conrady and Jouffe 2015). Survey data reflect the perceptions and knowledge of human beings but are fraught with high levels of uncertainty - BBNs are capable of dealing with such uncertainty effectively and efficiently (Chen and Pollino 2012). These capabilities of BBNs were applicable to the research problem, particularly for analyzing the study's relatively small sample size and where data were based on perceptions expressed in a categorical nature. BBNs were selected as the primary analysis method; a schematic of analytical methods and associated techniques are reproduced in Figure 1 for brevity.

<INSERT FIGURE 1 HERE>

Unsupervised learning through the Maximum Weight Spanning Tree (MWST) algorithm was utilized due to its proven efficiency and simplicity to identify associations among variables in a dataset. Given, the nature of variables, following a non-normal distribution, Minimum Description Length (MDL) scoring was implemented. BBNs also enable researchers to concurrently integrate theories with knowledge extracted from the dataset for analytic modelling (Conrady and Jouffe 2015). Therefore, models submitted to supervised learning were deemed capable of integrating the associations identified through unsupervised learning with previous findings from the literature (see Figure 1). Supervised learning focuses on exploring a target variable in the model, particularly to identify the most relevant variables in characterization of the target node by comparing the strength of associations among a target and its predictors. The most efficient variable selection technique for BBNs is Markov Blanket (Conrady and Jouffe 2015), which was the primary technique used to identify the most relevant variables affecting target variables. BBNs are natively probabilistic, omni-directional and capable of trying out various scenarios to capture the uncertainty of human perceptions. The entire joint probability distribution of variables in the system were included to handle different scenarios regarding the problem, using Conditional Probability Tables (CPTs). These tables act as inference engines using monitors for variables, and enable researchers of setting evidence for variables in the model, and simulating various scenarios, in order to perform reasoning. Using CPTs however, necessitated developing a model to define the associations between the variables included. The commercially available BayesiaLab software was used to conduct the analysis (c.f. Conrady and Jouffe (2015), as this package provides a complete set of Bayesian network tools including unsupervised and supervised learning.

Findings of the Study

Once a BBN model is fully specified, CPTs can compute the underlying probabilities and the strength of associations between variables in view of the assumptions or evidence about the state of the parents of variables (Chen and Pollino 2012). The rule at the very heart of the BBN analysis suggests that if $\boldsymbol{x_i}$ is some value for the variable $\boldsymbol{X_i}$ and $\boldsymbol{pa_i}$ represents some set of values for the parents of $\boldsymbol{X_i}$, then $\boldsymbol{P}(\boldsymbol{x_i}|\boldsymbol{pa_i})$ indicates this conditional probability distribution. Generally, the global semantics of BBNs specifies that the full joint probability distribution (JPD) is given by the chain rule, illustrated in Equation 1.

$$P(x_i, \dots\dots\dots., x_n) = \prod_i P(x_i|pa_i) \qquad \text{Equation 1}$$

To build the engagement model (refer to Figure 2), attributes of SMEs along with their BIM implementation levels were included as variables. Associations were defined based on the review of literature to incorporate the impacts of s*ize*, e*xperience*, *role*, and c*lient* (four predictors) on i*mplementation level* of SMEs (the target variable). To integrate these associations with the knowledge provided by the dataset, unsupervised learning was conducted through a MWST algorithm and MDL scoring method, in order to capture any dependencies between the variables. This resulted in identifying a link between the s*ize* and the c*lient*, as illustrated in Figure 2.

<INSERT FIGURE 2 HERE>

The strength of associations between variables in a model can be accurately assessed using the concept of *mutual information*, which is reflected in the value of *Arc's Mutual Information* between variables. Arc's Mutual Information value shows which variable as the predictor provides the maximum information, thus has the greatest importance to predict the state of the target node in the model. Specifically, the value indicates the state of each variable in the model and what percentage uncertainty will be reduced for the variable on the opposing side of the link (Conrady and Jouffe 2015). Arc's Mutual Information value is calculated using Equation 2 for any pair of variables such as (x, y) (c.f. Conrady and Jouffe (2015) for further details).

$$I\ (x, y) = \sum_{x \in X} \sum_{y \in Y} p(x, y) \log_2 \frac{p(x,y)}{p(x)p(y)} \qquad \text{Equation 2}$$

Having performed the supervised learning analysis of nodes through Markov Blanket, the model in Figure 2 demonstrates the values (highlighted in blue) of Arc's Mutual Information between the variables on both sides of the links. That is, knowing the size of a company, means that uncertainty regarding its BIM implementation level can be reduced by 3.56% on average. Similarly, awareness of the amount of experience of a SME in the market and the type of client can reduce the level of uncertainty on BIM implementation level by 2.95% and 2.98% (on average) respectively. Given, the low values provided by the model, a relationship analysis was conducted to assess whether associations are significant (refer to Table 3).

<INSERT TABLE 3 HERE>

BayesiaLab assesses the dependency using two different approaches, namely: i) *G-test* of independence; and ii) *Kullback-Leibler Divergence*. The G-test tests the dependency on categorical or nominal variables, to assess the dependency of proportions, whereas *Kullback-Leibler Divergence* is an information-based test of disparity among probability distributions of variables (c.f. Joyce (2011) for a comprehensive treatment of this subject). As illustrated in Table 3, for both the tests, *p-values* were well above 0.05, indicating no significant association between s*ize*, *role*, e*xperience*, and c*lient* with BIM *implementation level*. That is, none of these characteristics define the level of BIM implementation for SMEs. SMEs in any size, with any level of experience, in all typical roles, and clientele have similar behavior towards BIM use.

Barriers to BIM use in higher maturity

To analyze the associations between different levels of BIM implementation and barriers to each one, the 4-levelled categorization of BIM maturity was used. The barriers identified from the literature (see Table 1) were defined as the variables. An unsupervised learning through a MWST algorithm and MDL scoring method was performed to reveal any hidden association among the included variables. This resulted in identifying associations between 'Barr 04' (*perceived low benefits of BIM*) with 'Barr 01' (*lack of demand for high-level of BIM implementation*) and 'Barr 10' (*perception of limited functionality of higher levels of BIM for SMEs*). The level of BIM implementation was defined as the target variable and barriers were considered as predictors of this target variable. These considerations resulted in the creation of the model illustrated in Figure 3.

<INSERT FIGURE 3 HERE>4

The dependency among the variables included in the model was assessed through two different tests of dependency for categorical and nominal variables. As such, the *G-test* of independence, and *Kullback-Leibler Divergence* were performed (refer to Table 4) and illustrated that none of the barriers were significantly associated with the level of implementation. There was no meaningful association between the barriers and the change in levels of BIM implementation. Consequently, the included barriers can be deemed similarly influential in BIM use, preventing companies from moving from Level 0 to Level 1, from Level 1 to Level 2, and from Level 2 to Level 3.

<INSERT TABLE 4 HERE>

Nevertheless, the associations between Barr 04 and Barr 01, and Barr 04 with Barr 10 were found to be significant, with both techniques showing *p-values* below 0.05 (see Table 4). To identify the most influential barriers affecting the level of implementation, a CPT was utilized, linking the level of implementation as the target, and barriers as predictors of this target variable. The barriers were sorted based on the mutual information values and calculated based on Equation 2. That is, the level of influence of barriers was defined according to the amount of information that each one provides, to predict the level of implementation of BIM in SMEs (refer to Figure 4).

<INSERT FIGURE 4 HERE>

Based upon Figure 4 and Table 4, the most influential barriers were found to be Barr 10, Barr 04, and Barr 01, which can be attributed to the limited perceived functional value of migrating to higher levels of BIM, along with the adequacy of current levels. The second group of sorted barriers all referred to the required resources for shifting to higher levels of BIM. That is, Barr 05 (significant transition costs for BIM implementation), Barr 02 (*lack of knowledge on managing the process of BIM adoption*) and Barr 03 (*shortage of skills and expertise for high-level of BIM implementation*). The barriers that displayed the least amount of influence were found to be Barr 11 (*immaturity of BIM technology for high-level of BIM implementation*), Barr 06 (*lack of clients' demand of BIM use*) and Barr 09 (*perceived lack of suitability of BIM for all building project types*). These for the most part were reflective of particular features of the projects delivered by SMEs, such as the lack of functionality of BIM for the project delivered by the company and lack of interest from clients in such projects.

Discussion of the Findings

The study's findings revealed certain original views and new insights with regard to BIM use in Australian SMEs. Overall, the study's theoretical contribution provided a pragmatic view of BIM use by studying both adoption and implementation from the perspective of construction SMEs (and thus interacting with both intra- and inter-organizational levels), as underlined by the CDP perspective. The study adds to an existing knowledge base of SMEs' BIM use by offering empirical data collated through questionnaires, outlined from scientific research and analyzed in a robust quantitiative manner. Specifically, the study demonstrated no meaningful association between the attributes of SMEs and their level of BIM implementation. Previous studies such as McGraw-Hill (2014) highlighted the discrepancies between SMEs and large-sized Australian companies in using BIM, using descriptive statistics. Dainty et al. (2017) maintained that SMEs' attributes such as size are determinants of BIM engagement. The findings of this empirical research however, do not uphold these assumptions. These challenging new findings could be explained in view of the trade-off between structural and organizational flexibility and agility in smaller and newly-established SMEs, and availability of assets and resources in larger and mature ones (Amit and Schoemaker 1993). Another explanation could be the impact of context in shaping the nature of associations among attributes of companies and their behaviors towards an innovation (Rosenbusch et al. 2011). SMEs idiosyncrasies in synergy with BIM specific requirements might act as moderators to neutralize the impacts of firms' demographics.

Study findings also reveal that the key barriers preventing SMEs from implementing BIM in higher and more sophisticated maturity levels, almost entirely stemmed from the lack of solid evidence of concomitant financial benefits. The same barrier prevented SMEs from adopting BIM, as previously argued by Hosseini et al. (2016). This insight underlines the crucial role of providing a better understanding of measures for transforming BIM capabilities into tangible marketable outputs in

SMEs for projects typically delivered. The limitations of SMEs in terms of available resources and knowledge were also influential barriers. Reaping the benefits of BIM in higher levels of implementation relies on establishing collaborative relationships with external entities involved in projects (Oraee et al. 2017). From the perspective of CDP, using innovative methodologies with a focus on external collaboration is fraught with risks for SMEs - that is, complicated, collaboration-oriented innovative methodologies become substantially challenging for SMEs and incur great costs (Rosenbusch et al. 2011). As smaller market participants, SMEs must follow the instructions and interests of larger organizations, and receive unfavorable terms in such collaborative relationships (Porter 2004). There is thus, additional scope to support continuous engagement of SMEs with BIM use in order to avert the impressions of a 'digital divide' that currently dominates BIM rhetoric and support a more collaborative and less competitive view of BIM in construction.

Practical Implications

Drawing upon the findings, several practical implications are suggested to promote higher levels of BIM implementation among SMEs. First, according to CDP principles, directing SMEs towards higher levels of BIM implementation is achievable by providing insights into how such a migration could be translated into profit and higher performance (Ketchen et al. 2004). This point was argued by Hosseini et al. (2016), as a remedial solution to increase the BIM adoption rate among SMEs. To mitigate the issues involved with risky, competitive and unfavorable collaborative relationships with larger organizations who exhibit a natural propensity to implement BIM at higher levels, SMEs are advised to consider developing internally-designed BIM solutions and engage in external collaborations in a dynamic manner. Initially, focusing on internal BIM development, as better insights and market recognition is gained, the focus of SMEs can progressively shift towards actively engaging with external collaborators to leverage their experiences and capabilities in BIM (Rosenbusch et al. 2011). Essentially, SMEs could manage BIM knowledge and increase their BIM learning through partnering and alliances (Papadonikolaki and Wamelink 2017). Another solution might be engaging in collaborations with other SMEs (as external partners) at initial stages where competitive dynamics are favorable and the liability of smallness is less detrimental (Rosenbusch et al. 2011).

The research findings also warrant further scrutiny of plans to pursue mandating BIM in Australia. As discussed, power relations within companies engaged in a mandated BIM collaboration network along with the inherent problems facing SMEs (such as lack of resources), might render an enforced BIM implementation strategy deeply troubling for SMEs. These perceived draconian conditions widen the knowledge and technical capabilities gap, and engender business inequality between SMEs with large-sized companies. These inequalities among construction firms tend to become more extreme in top-down BIM diffusion mechanisms (Succar and Kassem 2015), in contexts where BIM is mandated. Such a situation is counter-intuitive given the construction industry's reliance upon SMEs who often sub-contract for larger contractors and so other more encouraging and engaging strategies should be sought.

Conclusions

The study contributed to the body of knowledge on BIM-related studies devoted to BIM use amongst SMEs in several ways. First, the study is among the few that transcend the dominant approach of focusing on adoption of BIM and investigating adoption/ non-adoption behaviors. That is, the present study moves to the area of implementation and mature levels of BIM use. Second, several original insights into the problem were revealed and as such, will engender wider debate as well as encourage further investigation into the impacts of SMEs' attributes on their behaviors towards BIM use. Moreover, the findings validate the assumption that considerations are at the forefront of SME decision making regards the level of BIM implementation. A new insight proposed is the detrimental consequences of dependence on external collaboration in engaging with BIM. This also triggers further debate on the assessment of long-term consequences of BIM mandating in widening the gap between SMEs and large-sized companies in the market, an area hitherto overlooked within extant literature.

Despite these various contributions, the research has several limitations. The findings are reflective of perceptions from the context of Australian SMEs and predominantly micro-sized companies. As a result, direct translation of the findings into guidelines in other countries and for companies with glaringly different attributes should be treated with caution. This limitation however, points towards several fertile grounds for further investigation into the topic, including: assessing the validity of the findings in other contexts and countries; use of larger sample sizes; and incorporation of other interested stakeholders such as clients - where this study was limited to contractors and design companies. The focus of such future work should seek to provide additional insight into the mechanics of collaboration between SMEs, designers, clients and large-sized companies in engaging with BIM.

References

Acar, E., Koçak, I., Sey, Y., and Arditi, D. (2005). "Use of information and communication technologies by small and medium-sized enterprises (SMEs) in building construction." *Constr. Manage. Econ.*, 23(7), 713-722.

Aibinu, A., and Venkatesh, S. (2014). "Status of BIM adoption and the BIM experience of cost consultants in Australia." *Journal of Professional Issues in Engineering Education and Practice*, 140(3), 04013021.

Amit, R., and Schoemaker, P. J. (1993). "Strategic assets and organizational rent." *Strategic management journal*, 14(1), 33-46.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., and O'Reilly, K. (2011). "BIM adoption and implementation for architectural practices." *Struct. Surv.*, 29(1), 7-25.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., and O'Reilly, K. (2011). "Technology Adoption in the BIM implementation for Lean Architectural Practice." *Autom Constr*, 20, 189-195.

Ashcraft, H. W. (2008). "Building information modeling: A framework for collaboration." *Constr. Law.*, 28(3), 5-18.

Azhar, S. (2011). "Building Information Modeling (BIM): Trends, benefits, risks and challenges for the AEC industry." *Leadersh. Manage. Eng.*, 11(3), 241–252.

Barata, J. M., and Fontainha, E. (2017). "Determinants of innovation in European construction firms." *Technological and Economic Development of Economy*, 23(6), 915-936.

Becerik-Gerber B., G. D. J., Ku K. (2011). "The pace of technological innovation in architecture, engineering, and construction education: integrating recent trends into the curricula." *Electronic Journal of Information Technology in Construction (ITcon)*, 16, 411-432.

Ben, K. D., Juan-Diego, Z.-R., and Gordon, I. M. (2007). "A Bayesian Belief Network Approach for Modeling Complex Domains." *Bayesian Network Technologies: Applications and Graphical Models*, IGI Global, Hershey, PA, USA, 13-41.

Bing, L., Akintoye, A., Edwards, P. J., and Hardcastle, C. (2005). "The allocation of risk in PPP/PFI construction projects in the UK." *Int. J. Proj. Manage.*, 23(1), 25-35.

Bröchner, J., and Lagerqvist, O. (2016). "From ideas to construction innovations: firms and universities collaborating." *Construction Economics and Building*, 16(1), 76-89.

Cao, D., Li, H., and Wang, G. (2014). "Impacts of Isomorphic Pressures on BIM Adoption in Construction Projects." *J Constr Eng Manage*, 140(12), 04014056.

Cao, D., Li, H., Wang, G., and Huang, T. (2017). "Identifying and contextualising the motivations for BIM implementation in construction projects: An empirical study in China." *Int. J. Proj. Manage.*, 35(4), 658-669.

Chen, M.-J., and Miller, D. (2012). "Competitive Dynamics: Themes, Trends, and a Prospective Research Platform." *The Academy of Management Annals*, 6(1), 135-210.

Chen, S. H., and Pollino, C. A. (2012). "Good practice in Bayesian network modelling." *Environmental Modelling & Software*, 37, 134-145.

Chong, H.-Y., Fan, S.-L., Sutrisna, M., Hsieh, S.-H., and Tsai, C.-M. (2017). "Preliminary Contractual Framework for BIM-Enabled Projects." *J Constr Eng Manage*, 143(7), 04017025.

Conrady, S., and Jouffe, L. (2015). *Bayesian Networks and BayesiaLab A Practical Introduction for Researchers*, Bayesia USA, Franklin, TN.

Dainty, A., Leiringer, R., Fernie, S., and Harty, C. (2017). "BIM and the small construction firm: a critical perspective." *Building Research & Information*, 45(6), 696-709.

Davies, R., and Harty, C. (2013). “Implementing ‘Site BIM’: a case study of ICT innovation on a large hospital project.” *Autom Constr*, 30, 15-24.

Demian, P., and Walters, D. (2014). “The advantages of information management through building information modelling.” *Constr. Manage. Econ.*, 32(12), 1153-1165.

Dossick, C. S., and Neff, G. (2010). “Organizational Divisions in BIM-Enabled Commercial Construction.” *J Constr Eng Manage*, 136(4), 459-467.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., and McNiff, S. (2013). “BIM implementation throughout the UK construction project lifecycle: An analysis.” *Autom Constr*, 36(Supplement C), 145-151.

Elmualim, A., and Gilder, J. (2014). “BIM: innovation in design management, influence and challenges of implementation.” *Arch. Eng. Des.*, 10(3-4), 183-199.

Forsythe, P. “The Case for BIM Uptake among Small Construction Contracting Businesses.” *Proc., Proceedings of the 31st International Symposium on Automation and Robotics in Construction and Mining*, University of Technology Sydney.

Ganah, A., and John, G. A. (2014). “Achieving Level 2 BIM by 2016 in the UK.” *Computing in Civil and Building Engineering (2014)*, 143-150.

Gledson, B. J. (2016). “Hybrid project delivery processes observed in constructor BIM innovation adoption.” *Constr. Innov.*, 16(2), 229-246.

Goucher, D., and Thurairajah, N. “Advantages and challenges of using BIM: A cost consultant's perspective.” *Proc., 49th ASC Annual International Conference, California Polytechnic State University (Cal Poly), San Luis Obispo, California*.

Grilo, A., and Jardim-Goncalves, R. (2010). “Value proposition on interoperability of BIM and collaborative working environments.” *Automation in Construction*, 19(5), 522-530.

Hosseini, M. R., Banihashemi, S., Chileshe, N., Namzadi, M. O., Udaeja, C., Rameezdeen, R., and McCuen, T. (2016). “BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model.” *Construction Economics and Building*, 16(3), 71-86.

Jaradat, S., and Sexton, M. “BIM Articulation in different-sied Architectural firms.” *Proc., Proceedings of the 32nd Annual ARCOM Conference*, Association of Researchers in Construction Management, 63-72.

Joyce, J. M. (2011). “Kullback-Leibler Divergence.” *International Encyclopedia of Statistical Science*, M. Lovric, ed., Springer Berlin Heidelberg, Berlin, Heidelberg, 720-722.

Kale, S., and Arditi, D. (2010). “Innovation Diffusion Modeling in the Construction Industry.” *J Constr Eng Manage*, 136(3), 329-340.

Ketchen, D. J., Snow, C. C., and Hoover, V. L. (2004). “Research on Competitive Dynamics: Recent Accomplishments and Future Challenges.” *Journal of Management*, 30(6), 779-804.

Khosrowshahi, F., and Arayici, Y. (2012). “Roadmap for implementation of BIM in the UK construction industry.” *Engineering, Construction and Architectural Management*, 19(6), 610-635.

Killip, G. (2013). “Products, practices and processes: exploring the innovation potential for low-carbon housing refurbishment among small and medium-sized enterprises (SMEs) in the UK construction industry.” *Energy Policy*, 62, 522-530.

Lam, T. T., Mahdjoubi, L., and Mason, J. (2017). “A framework to assist in the analysis of risks and rewards of adopting BIM for SMEs in the UK.” *J. Civ. Eng. Manage.*, 23(6), 740-752.

Lee, S., and Yu, J. (2016). “Comparative Study of BIM Acceptance between Korea and the United States.” *J Constr Eng Manage*, 142(3), 05015016.

Lee, S., Yu, J., and Jeong, D. (2015). "BIM Acceptance Model in Construction Organizations." *J Manage Eng*, 31(3), 04014048.

Liang, C., Lu, W., Rowlinson, S., and Zhang, X. (2016). "Development of a Multifunctional BIM Maturity Model." *J Constr Eng Manage*, 142(11), 06016003.

Love, P. E., Liu, J., Matthews, J., Sing, C.-P., and Smith, J. (2015). "Future proofing PPPs: Life-cycle performance measurement and building information modelling." *Autom Constr*, 56, 26-35.

Mackenzie, N., and Knipe, S. (2006). "Research dilemmas: Paradigms, methods and methodology." *Issues in educational research*, 16(2), 193-205.

Manderson, A., Jefferies, M., and Brewer, G. (2015). "Building information modelling and standardised construction contracts: a content analysis of the GC21 contract." *Construction Economics and Building*, 15(3), 72-84.

Manley, K. (2008). "Against the odds: Small firms in Australia successfully introducing new technology on construction projects." *Research Policy*, 37(10), 1751-1764.

Mayo, G., Giel, B., and Issa, R. R. (2012). "BIM use and requirements among building owners." *International Conference on Computing in Civil Engineering* R. R. Issa, and I. Flood, eds.Clearwater Beach, Florida, United States, 349-356.

McGraw-Hill (2012). *The business value of BIM for Construction in North America: Multi-Year trend Analysis and User Ratings (2007-2012)*, McGraw Hill Construction, Bedford, MA.

McGraw-Hill (2014). *The business value of BIM for Construction for Owners*, McGraw Hill Construction, Bedford, MA.

McGraw-Hill (2014). *The business value of BIM in Australia and New Zealand: How building information modelling is transforming the design and construction industry*, McGraw Hill Construction, Bedford, MA.

Murphy, M. (2014). "Implementing innovation: a stakeholder competency-based approach for BIM." *Constr. Innov.*, 14(4), 433-452.

NBS (2014). "NBS National BIM Report." <https://www.thenbs.com>. (08 August 2017).

Neuman, W. L. (2006). *Social research methods : qualitative and quantitative approaches*, Pearson/Allyn and Bacon, Boston.

Oraee, M., Hosseini, M. R., Papadonikolaki, E., Palliyaguru, R., and Arashpour, M. (2017). "Collaboration in BIM-based construction networks: A bibliometric-qualitative literature review." *Int. J. Proj. Manage.*, 35(7), 1288-1301.

Papadonikolaki, E., Verbraeck, A., and Wamelink, H. (2017). "Formal and informal relations within BIM-enabled supply chain partnerships." *Constr. Manage. Econ.*, 1-22.

Papadonikolaki, E., Vrijhoef, R., and Wamelink, H. (2016). "The interdependences of BIM and supply chain partnering: Empirical explorations." *Architectural Engineering and Design Management*.

Papadonikolaki, E., and Wamelink, H. (2017). "Inter- and intra-organizational conditions for supply chain integration with BIM." *Building Research & Information*, 1-16.

Poirier, E., Staub-French, S., and Forgues, D. (2015). "Embedded contexts of innovation: BIM adoption and implementation for a specialty contracting SME." *Constr. Innov.*, 15(1), 42-65.

Porter, M. E. (2004). *Competitive advantage : creating and sustaining superior performance*, Free Press, New York.

Porwal, A., and Hewage, K. N. (2013). "Building Information Modeling (BIM) partnering framework for public construction projects." *Autom Constr*, 31(0), 204-214.

Robson, C. (2002). *Real world research*, Blackwell publishers Oxford.

Rosenbusch, N., Brinckmann, J., and Bausch, A. (2011). "Is innovation always beneficial? A meta-analysis of the relationship between innovation and performance in SMEs." *Journal of Business Venturing*, 26(4), 441-457.

Saridakis, G., Muñoz Torres, R., and Johnstone, S. (2013). "Do human resource practices enhance organizational commitment in SMEs with low employee satisfaction?" *British Journal of Management*, 24(3), 445-458.

Shelton, J., Martek, I., and Chen, C. (2016). "Implementation of innovative technologies in small-scale construction firms: Five Australian case studies." *Eng. Constr. Archit. Manage.*, 23(2), 177-191.

SMEAA (2011). "SME infographic illustrates vital role of sector in Australian economy." SME Association of Australia (SMEAA), http://www.smea.org.au/.

Smith, K. G., Ferrier, W. J., and Ndofor, H. (2001). "Competitive dynamics research: Critique and future directions." *Handbook of strategic management*, M. Hitt, R. E. Freeman, and J. Harrison, eds., Blackwell Publishers, London, 315-361.

Stanley, R., and Thurnell, D. (2014). "The benefits of, and barriers to, implementation of 5D BIM for quantity surveying in New Zealand."

Succar, B. (2009). "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Autom Constr*, 18(3), 357-375.

Succar, B., and Kassem, M. (2015). "Macro-BIM adoption: Conceptual structures." *Autom Constr*, 57, 64-79.

Ueapme (2017). "European Association of Craft Small and Medium-Sized Enterprise: Construction ", <http://www.ueapme.com>. (25 August, 2017).

Won, J., Lee, G., Dossick, C., and Messner, J. (2013). "Where to focus for successful adoption of building information modeling within organization." *J Constr Eng Manage*, 139(11), 04013014.

Wu, C., Xu, B., Mao, C., and Li, X. (2017). "Overview of BIM maturity measurement tools." *Journal of Information Technology in Construction (ITcon)*, 22(3), 34-62.

Yan, H., and Demian, P. (2008). "Benefits and barriers of building information modelling."

Table 1. Barriers to BIM implementation

Barr No.	Barrier	Type	Source(s)
01	Lack of demand for high-level of BIM implementation	Demand	Aibinu and Venkatesh 2014; Goucher and Thurairajah 2012; Won et al. 2013.
02	Lack of knowledge on managing the process of BIM adoption	Resources	Aibinu and Venkatesh 2014; Becerik-Gerber B. 2011; Won et al. 2013.
03	Shortage of skills and expertise for high-level of BIM implementation	Supply	Papadonikolaki et al. 2016; Papadonikolaki and Wamelink 2017; Yan and Demian 2008.
04	Perceived low benefits of BIM	Motivation	Dainty et al. 2017; McGraw-Hill 2012.
05	Significant transition costs for BIM implementation	Resources	Aibinu and Venkatesh 2014; McGraw-Hill 2012; Stanley and Thurnell 2014; Yan and Demian 2008; Ganah and John 2014.
06	Lack of clients' demand of BIM use	Demand	Aibinu and Venkatesh 2014; Goucher and Thurairajah 2012.
07	Insufficient clients' knowledge about BIM implementation	Demand	Goucher and Thurairajah 2012.
08	Shortage of BIM knowledge and expertise across lower supply chain tiers	Supply	Papadonikolaki et al. 2016; Papadonikolaki and Wamelink 2017.
09	Perceived lack of suitability of BIM for all building project types	Demand	Yan and Demian 2008; Won et al. 2013.
10	Perception of limited functionality of higher levels of BIM for SMEs	Motivation	Hosseini et al. 2016; McGraw-Hill 2012.
11	Immaturity of BIM technology for high-level of BIM implementation	Motivation	Aibinu and Venkatesh 2014; Demian and Walters 2014; Grilo and Jardim-Goncalves 2010; Stanley and Thurnell 2014; Arayici et al. 2011.

Table 2. Profile of participates

			Client / Experience								
			Government		Individual / Owner			Private organizations			Grand Total
Role	Position	Size	11-20 years	More than 20 years	11-20 years	More than 20 years	Up to 10 years	11-20 years	More than 20 years	Up to 10 years	
Contractor/Builder	Designer	5-19 employees				1					1
		20-199 employees				1			1		2
	Director	0-4 employees		3	4	12					19
		5-19 employees			6	8	1	2	1		18
		20-199 employees		1							1
	Project Manager	0-4 employees			2	2		1			5
		5-19 employees	1			1	2	1	1		6
Designer	Designer	0-4 employees			3	5					8
		5-19 employees				1			1	1	3
		20-199 employees						1			1
	Director	0-4 employees			8	31	5	2	4	1	51
		5-19 employees		2		4		2	5	1	14
		20-199 employees				1			3		4
	Engineer	20-199 employees						1			1
	Project Manager	5-19 employees			1						1
Grand Total			1	6	24	67	8	10	16	3	135

Table 3. Test of dependency between variables

Parent	**Child**	**Kullback-Leibler Divergence**	**Degrees of Freedom**	***p-value***	**G-test**	**Degrees of Freedom**	***p-value***
Experience	Implementation_Level	0.2715	144	100.0000%	10.4519	8	23.4732%
Size	Implementation_Level	0.2683	144	100.0000%	13.7376	8	8.8866%
Client	Implementation_Level	0.2093	144	100.0000%	10.5342	8	22.9515%
Role	Implementation_Level	0.2046	108	100.0000%	10.6702	4	3.0532%
Size	Client	0.1296	4	0.0071%	24.2571	4	0.0071%

Table 4. Test of dependency between the level of BIM implementation and barriers

Parent	**Child**	**Kullback-Leibler Divergence**	**Degrees of Freedom**	***p-value***	**G-test**	**Degrees of Freedom**	***p-value***
Barr 04	Barr 10	0.3808	4	0.0026%	26.3968	4	0.0026%
Barr 04	Barr 01	0.3606	4	0.0050%	24.9981	4	0.0050%
Barr 09	Implementation Level	0.0139	26244	100.0000%	1.7402	4	78.3410%
Barr 06	Implementation Level	0.0139	26244	100.0000%	1.4796	4	83.0243%
Barr 02	Implementation Level	0.0130	26244	100.0000%	2.5022	4	64.4241%
Barr 03	Implementation Level	0.0129	26244	100.0000%	2.8471	4	58.3731%
Barr 11	Implementation Level	0.0121	26244	100.0000%	1.6802	4	79.4311%
Barr 05	Implementation Level	0.0106	26244	100.0000%	4.1651	4	38.4129%
Barr 10	Implementation Level	0.0103	26244	100.0000%	6.9927	4	13.6277%
Barr 01	Implementation Level	0.0091	26244	100.0000%	2.9615	4	56.4296%
Barr 04	Implementation Level	0.0065	26244	100.0000%	1.7349	4	78.4367%

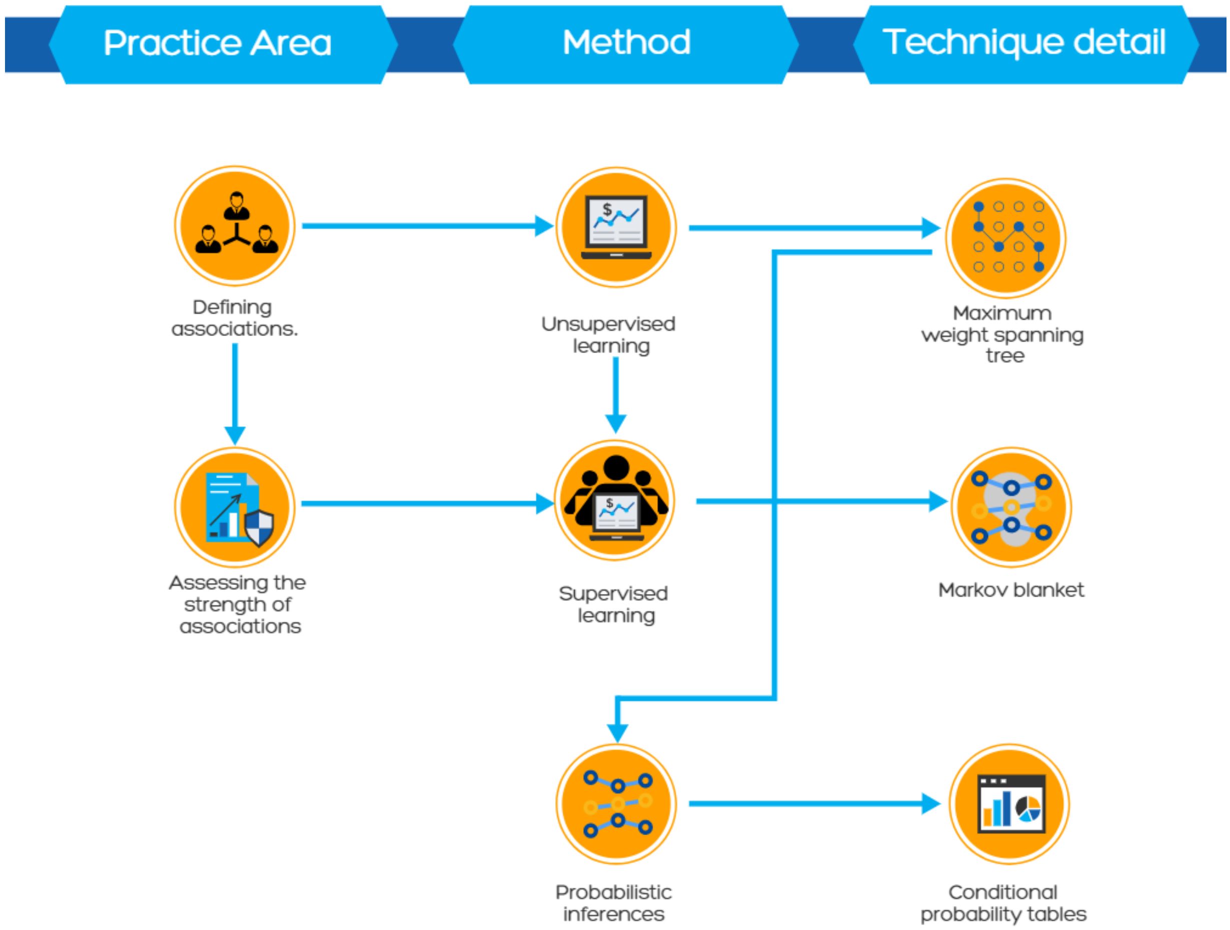

Figure 1. Methods and techniques used analyzing data

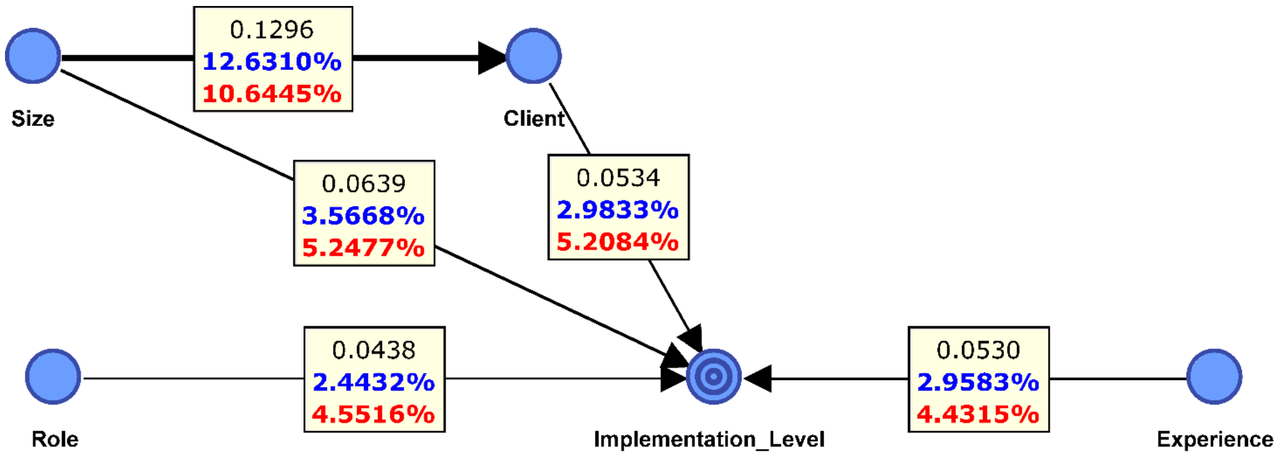

Figure 2. SMEs' characteristics and BIM implementation levels (note that the arrows illustrated are not indicating causal direction)

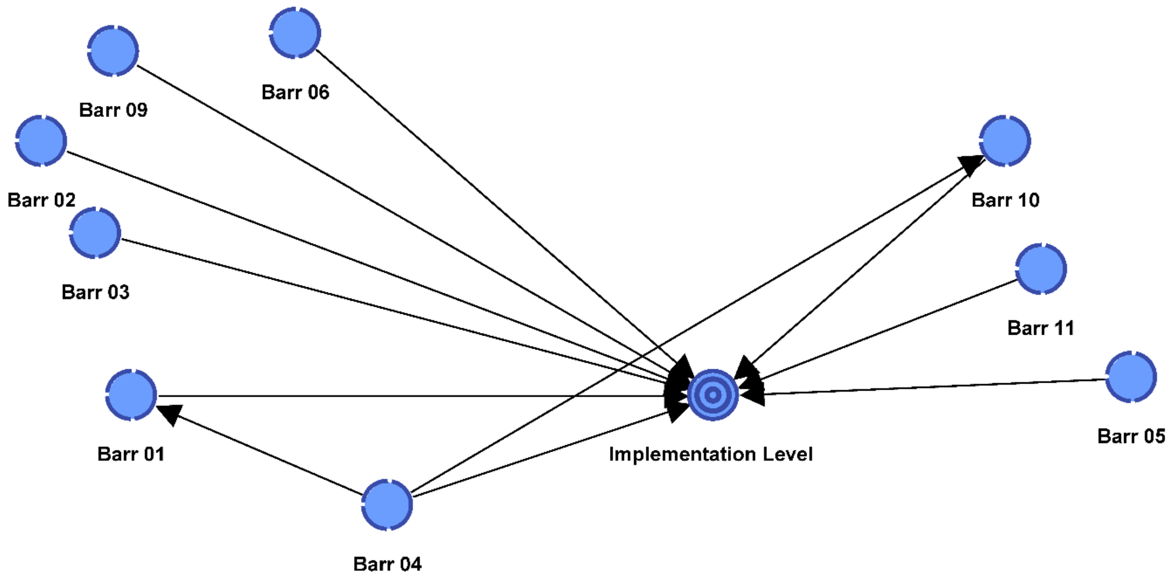

Figure 3. Association of levels of implementation with barriers (note that the arrows illustrated are not indicating causal direction)

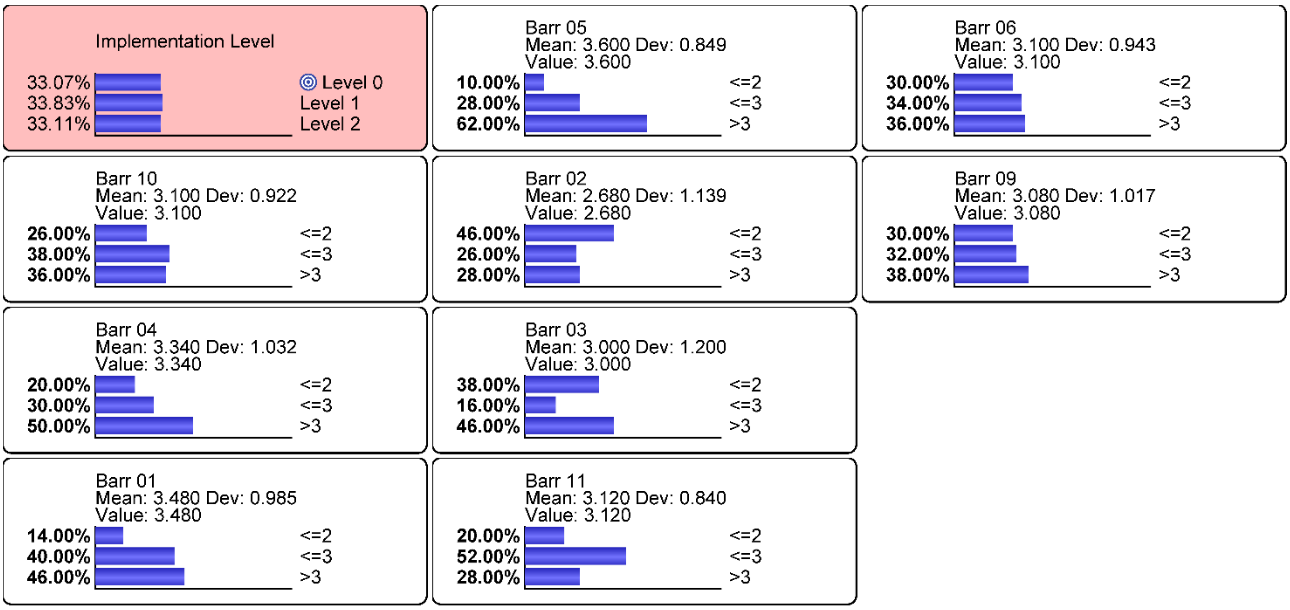

Figure 4. Sorted barriers to higher levels of implementation (sorted in columns, and left to right)