Macro BIM adoption: conceptual structures

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Highlights:

1. We overlay the concepts of BIM implementation and BIM diffusion to generate a unified definition of BIM adoption;
2. We introduce a Point of Adoption model for identifying and comparing the readiness, capability and maturity of organizations;
3. We introduce a conceptual reactor that feeds from existing conceptual structures, literature reviews and data collection efforts to generate new conceptual structures;
4. We introduce five macro adoption models, their companion matrices and charts for use in assessing and comparing BIM adoption across countries; and
5. We set the scene for a new discussion covering market-wide BIM adoption and invite policy makers to assess or develop their country-specific BIM implementation/diffusion efforts.

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Abstract

Building Information Modelling (BIM) concepts and workflows continue to proliferate within organizations, through project teams, and across the whole construction industry. However, both BIM implementation and BIM diffusion are yet to be reliably assessed at market scale. Insufficient research has been conducted to date towards identifying the conceptual structures that would explain and encourage large-scale BIM adoption. This paper introduces a number of macro adoption models, matrices and charts (Figure 1). These models can be used to systematically assess BIM adoption across markets, and inform the structured development of country-specific BIM adoption policies.

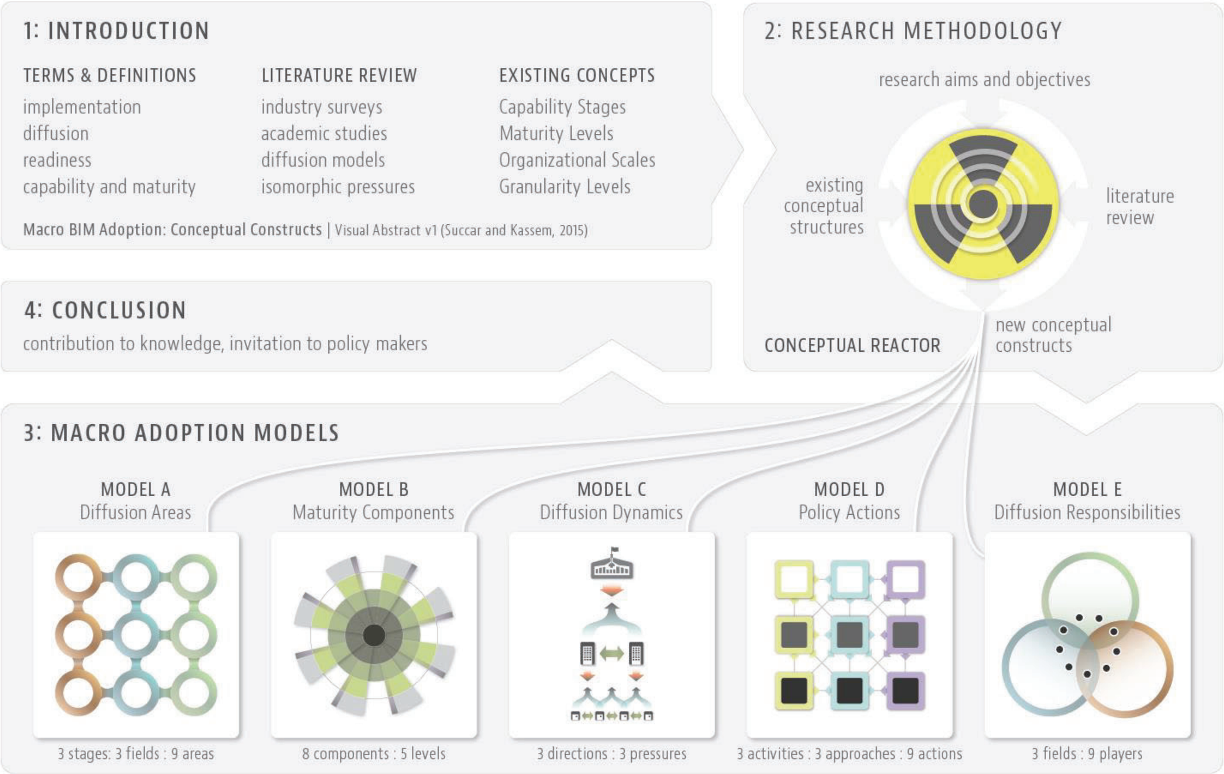

Figure 1. Visual Abstract

This research is published in two complementary papers combining conceptual structures with data collected from experts across a number of countries. The first paper "Macro BIM adoption: conceptual structures" delimits the terms used, reviews applicable diffusion models, and clarifies the research methodology. It then introduces five new conceptual constructs for assessing macro BIM adoption and informing the development of market-scale BIM diffusion policies. The second paper "Macro BIM adoption: comparative market analysis" employs these concepts and tools to evaluate BIM adoption and analyse BIM diffusion policies across a number of countries. Using online questionnaires and structured interviews, it applies the models, refines the conceptual tools and develops additional assessment metrics. The two papers are complementary and primarily intended to assist policy makers and domain researchers to analyse, develop and improve BIM diffusion policies.

Keywords: BIM Readiness, Capability and Maturity; BIM Implementation and Diffusion; Point of Adoption; BIM Framework Conceptual Reactor; BIM Diffusion Policy Development.

1. Introduction

Building Information Modelling (BIM) is the current expression of construction industry innovation, a set of technologies, processes and policies, affecting industry's deliverables, relationships and roles. BIM concepts and tools encourage concurrent revolutionary and evolutionary changes across organizational scales – from individuals and groups; through organizations and project teams; to industries and whole markets (Succar, 2010a). Investigations into BIM implementation across whole markets have been comparatively rare in spite of an ever-increasing range and depth of *national BIM initiatives* (NBI)s and *noteworthy BIM publications* (NBP)s (Kassem, Succar, & Dawood, 2013). More generally, there has been – and arguably still is – a dearth in investigations covering the diffusion of innovation within the construction industry (J. Taylor & Levitt, 2005). Available studies in market-scale BIM implementation and diffusion are dominated by survey ratings generated by commercially-driven service providers. The most prominent of these include: BIM diffusion in the UK, France and Germany (McGraw-Hill-Construction, 2010); Autodesk software uptake in Europe (Autodesk, 2011); BIM diffusion in the U.S. and Canada (McGraw-Hill-Construction, 2012); BIM diffusion in the UK (NBS, 2013) (NBS, 2014); The Business Value of BIM in Australia and New Zealand (McGraw-Hill-Construction, 2014) among others. While these reports include useful information, they suffer from a number of shortcomings – they:

- Have unknown, remedial or biased population sampling and data collection methodologies;
- Do not differentiate between software acquisitions and actual adoption (Fichman & Kemerer, 1999);
- Mostly neglect non-software aspects of BIM adoption;
- Are neither based on an existing conceptual framework, nor propose a new one;
- Do not identify market gaps or reflect market-specific criteria; and
- Cannot be used by policy makers to facilitate BIM diffusion.

In addition to industry surveys, a number of academic investigations covering market-scale BIM implementation and diffusion have been conducted in recent years. These studies covered multiple countries including: Australia (Gu & London, 2010), China (Cao, Li, & Wang, 2014), Finland (Lehtinen, 2010), Iceland (Kjartansdóttir, 2011), India (Luthra, 2010), South Africa (Froise & Shakantu, 2014), Sweden (Samuelson & Björk, 2013), Taiwan (Mom, Tsai, & Hsieh, 2011), United Kingdom (Khosrowshahi & Arayici, 2012), United States (Gilligan & Kunz, 2007) (Liu, Issa, & Olbina, 2010), and multiple markets (Smith, 2014) (Panuwatwanich & Peansupap, 2013) (Wong, Wong, & Nadeem, 2010) (Zahrizan, Ali, Haron, Marshall-Ponting, & Abd, 2013). While these studies provide more rigorous information than industry reports, and contribute valuable insights into BIM diffusion trends and paths, they offer little practical assistance to policy makers intent on assessing current or developing new market-specific BIM diffusion policies.

Based on the aforementioned industry surveys and academic studies; and building-upon published conceptual structures (Succar, 2009, 2010a, 2013b) and earlier investigations (Kassem & Leusin, 2014; Kassem et al., 2013; Kassem, Succar, & Dawood, 2014), this research delivers a number of *macro classifications, taxonomies and models* dedicated to assessing and informing the development of BIM diffusion policies. This paper will first clarify relevant implementation and diffusion terminology, identify the research methodology, and then introduce five new conceptual models covering macro BIM adoption.

1.1. Terms, concepts and their interaction

The terms used to describe the act of implementing an innovative system/process are often confused with the terms used to describe the spread of this system/process within a *population* of adopters – be it within an organization or across a market. It is therefore prudent to delimit a number of terms before utilising them to clarify larger concepts or propose macro adoption models. This delimitation is both artificial and necessary: it is artificial as other researchers can recalibrate the connotations of the same terms to fit their own unique purposes. It is necessary due to the availability of a large number of relevant diffusion models (Pierce & Delbecq, 1977) (Saga & Zmud, 1993) (Fadel, 2012) which do not differentiate between the stages of implementation - e.g. between acceptance and routinization as in Cooper and Zmud (1990) - the mechanics of diffusion, and the pressures causing the shift from one stage to another.

In introducing and delimiting these terms, we also limit ourselves to BIM as an innovative set of tools, processes and policies within the construction industry. This limitation is also both artificial and necessary: it is artificial as implementation/diffusion models introduced later are arguably applicable to other innovations within and outside the construction industry (e.g. to GIS and PLM). It is necessary due to the dearth in investigations covering innovation diffusion within the construction industry (J. Taylor & Levitt, 2005) thus warranting a focused attention on industry-specific and, by extension, BIM-specific terms.

To avoid confusion, and as a general distinction, this paper differentiates between the notions of BIM implementation as the *successful adoption* of BIM tools and workflows within a *single organization*, and 'BIM diffusion' as the rate BIM tools and workflows are adopted across *markets*. Both BIM implementation at *sub-organizational* scales (e.g. individuals and groups) and BIM diffusion across the *globa*l construction industry are intently placed outside the scope of this paper. We also make use of the generic term 'adoption' to overlay the connotations of implementation and diffusion unto a single word, and we use the term 'macro' to focus the readers' attention on large collections of organizational adopters operating within defined national borders (countries).

1.2. Implementation

Implementation refers to the wilful activities of a single identifiable player[1] as it adopts a novel system/process to improve its current performance. More specifically, *BIM implementation* refers to the set of activities undertaken by an *organizational unit* to prepare for, deploy or improve its BIM deliverables (products) and their related workflows (processes). BIM implementation is introduced here as a three-phased approach separating an organization's *readiness* to adopt; *capability* to perform; and its performance *maturity*:

- BIM readiness is the *pre-implementation status* representing the propensity of an organization or organisational unit to adopt BIM tools, workflows and protocols. Readiness is expressed[2] as the *level of preparation*, the *potential to participate*, or the c*apacity to innovate*. Readiness can be measured using a variety of approaches – product-based, process-based, and overall maturity (Saleh & Alshawi, 2005) – and signifies the planning and preparation activities preceding implementation;
- BIM capability is the wilful *implementation* of BIM tools, workflows and protocols. BIM capability is achieved through well-defined *revolutionary stages* (object-based modelling, model-based collaboration, and network-based integration) separated by numerous *evolutionary steps*. BIM capability cover many technology, process and policy topics and is expressed as the *minimum ability* of an organization or team to deliver a measureable outcome; and
- BIM maturity (or post-implementation) is the *gradual and continual improvement* in quality, repeatability and predictability within available capabilities. BIM maturity is expressed as *maturity levels* (or performance improvement milestones) that organizations, teams and whole markets aspire to. There are five maturity levels: [a] Ad-hoc or *low maturity*; [b] Defined or *medium-low maturity*; [c] Managed or *medium maturity*; [d] Integrated or *medium-high maturity*; and [e] Optimised or *high maturity* (Succar, 2010b).

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[1] Depending on the 'scoping lens' applied, BIM players are either individuals, groups, organizational units, or whole organizations. BIM players, deliverables and their requirements have been extensively covered in earlier works (Succar, 2009).

[2] Definitions adopted from the e-commerce context as used by the Asia-Pacific Economic Cooperation (APEC), Center for International Development (CID) at Harvard University (CID, 2014).

1.3. Point of Adoption

The three implementation phases – readiness, capability, and maturity - are depicted in the Point of Adoption (PoA) model (Figure 2). As explained below, a PoA is a term identifying the juncture(s) where organizational readiness transform into organizational capability/maturity:

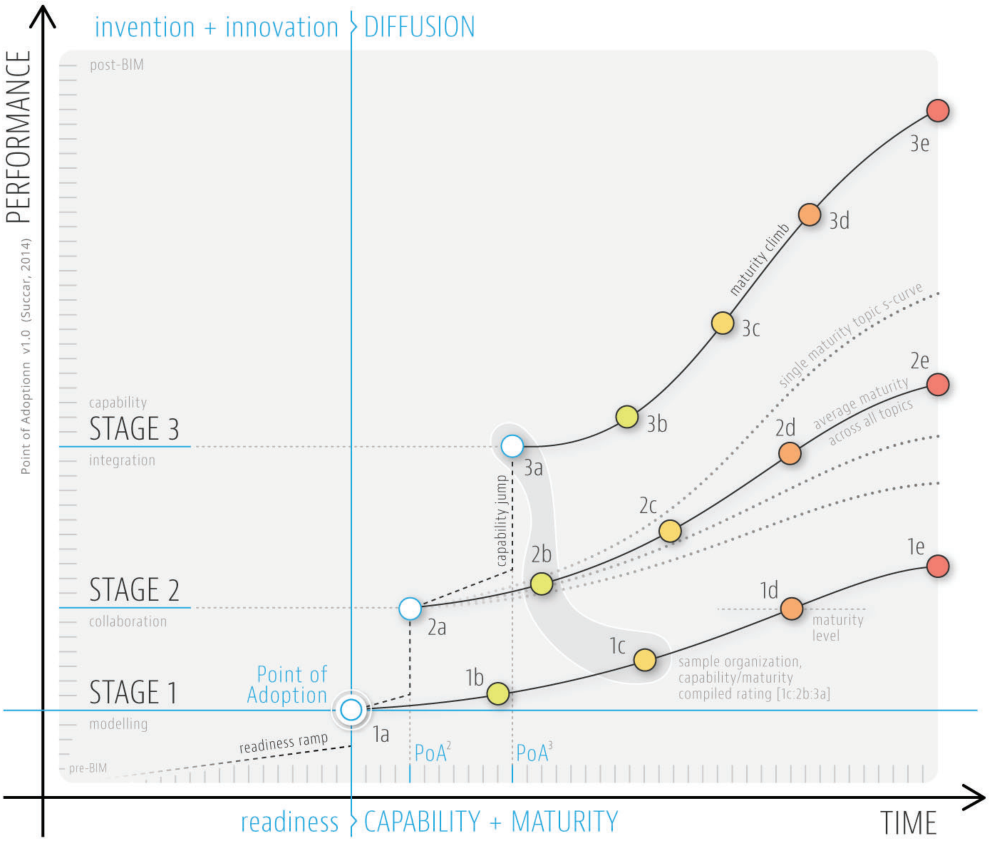

Figure 2. Point of Adoption *model v1.0* (full size, current version)

As explored in Figure 2, transformative BIM adoption starts at the Point of Adoption (PoA) when an organization, after a period of planning and preparation (readiness), successfully adopts *object-based modelling* tools and workflows. The PoA[3] thus marks the initial *capability jump* from no BIM abilities (pre-BIM status) to minimum BIM capability (Stage 1). As the adopter interacts with other adopters, a second capability jump (Stage 2) marks the organization's ability to successfully engage in model-based collaboration. Also, as the organisation starts to engage with multiple stakeholders across the supply chain, a third capability jump (Stage 3) is necessary to benefit from integrated, network-based tools, processes and protocols. Each of these capability jumps is preceded with considerable investment in human and physical resources, and each stage signals new organizational abilities and deliverables not available before the jump. However, the deliverables of different organizations at the same stage may vary in quality, repeatability and predictability. This variance in performance excellence occurs as organizations climb their respective BIM *maturity curve*, experience their internal BIM diffusion, and gradually improve their performance over time.

The multiple maturity curves depicted in Figure 2 reflect the heterogeneous nature of BIM adoption even within the same organization. This is due to the phased nature of BIM with each revolutionary stage requiring its own readiness ramp, capability jump, maturity climb, and point of adoption. This is also due to

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[3] The Point of Adoption (PoA) is not to be confused with the critical mass 'inflection point' on the S-curve (E. M. Rogers, 1995) (Everett M Rogers, Medina, Rivera, & Wiley, 2005); or with the 'tipping pint', the critical threshold introduced by Gladwell (2001).

varied abilities across organizational sub-units and project teams: while organizational unit A1 (within organization A) may have elevated *model-based collaboration* capabilities, unit A2 may have basic modelling capabilities, and unit A3 may still be preparing to implement BIM software tools. This variance in ability necessitates a compiled rating for organization A as it simultaneously prepares for an innovative solution, implements a system/process, and continually improves its performance.

1.4. Diffusion

In contrast to *implementation* which represents the successful adoption of a system/process by a single organization, diffusion represents the spread of the system/process within a *population* of adopters. That is, the diffusion of a solution occurs after the solution has been adopted (Peansupap & Walker, 2005) or what we termed earlier as the Point of Adoption (PoA). However, the mere acquisition of an innovative solution (e.g. a software) "need not be followed by widespread deployment and use by acquiring organizations" (Fichman & Kemerer, 1999, p. 256).

E. M. Rogers (1995, p. 5) defines diffusion as the "process by which an innovation is communicated through certain channels over time among the members of a social system", a definition that covers the increase in "number of firms using or owning a technology (inter-firm diffusion) [and the] more intensive use of the technology by the firm (intra firm diffusion)[4]" (Stoneman & Diederen, 1994, p. 919) (Mansfield, 1963). Diffusion is also identified as the third and final phase of the well-noted Schumpeterian Trilogy: "invention (the generation of new ideas), innovation (the development of those ideas through to the first marketing or use of a technology) and diffusion (the spread of new technology across its potential market)" (Stoneman & Diederen, 1994, p. 918). According to Stoneman (1995), as discussed in Mahdjoubi (1997, p. 2), diffusion is the phase where the true impact of new technology occurs and thus "the measurement of impact is very much a measurement of how the economy changes as new technologies are introduced and used."

There are numerous studies dedicated to innovation diffusion across a population of adopters (Bass, 2004; Kale & Arditi, 2010; Mansfield, Rapoport, Romeo, Wagner, & Beardsley, 1977; E. M. Rogers, 1995). These studies either explain and expand-upon the S-curve diffusion pattern (Cumulative Normal Distribution (Everett M Rogers et al., 2005) consistently encountered when analysing the spread of innovation; or introduce *diffusion models* that "depict the successive increases in the number of adopters and predict the continued development of a diffusion process already in progress" (Mahajan, Muller, & Bass, 1990b, p. 2).

According to Geroski (2000), there are two main types of diffusion models providing insights into the manner and speed of technology adoption – the epidemic model and the probit model. The 'epidemic' diffusion model attributes the diffusion of technology (software in particular) to a given population's knowledge of its existence; its comparative benefits; and the spread of its use through word of mouth. As it focuses on a whole population of adopters, the epidemic model is interested in the gradual, unfolding impact of a new system/process on a market through its aggregate use. This contrasts with the 'probit' and 'salience' diffusion models which focus on the effect of *individual decision-making* on the spread of innovation (Geroski, 2000, p. 614; Strang, 1991).

This individual decision-making affecting diffusion follows three identifiable patterns – contagion, social threshold and social learning (Young, 2006, p. 4): 'Contagion' represents how an industry player (e.g. an engineering company) adopts an innovative system/process upon contact with another player who has already adopted it; 'social threshold' represents how an industry player adopts an innovative system/process when *enough similar players* have adopted it; and 'social learning' represents how an industry player adopts an innovative system/process when *enough proof is available* of prior adopters finding it worth adopting. These inter-organizational diffusion patterns are further explained by DiMaggio

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[4] To avoid conceptual overlap, the spread of a solution within an organizational unit will not be referred to as intra-diffusion but as improved implementation (or higher level of maturity) across the whole organization.

and Powell (1983) as reflecting two sets of isomorphic pressures - *competitive* and *institutional*. Competitive isomorphic pressures are market forces (e.g. supply and demand dynamics) driving organizations towards similarity; while institutional isomorphic pressures involve “organizational competition for political and institutional legitimacy as well as market position” (Mizruchi & Fein, 1999, p. 657). As discussed by DiMaggio and Powell (1983), institutional pressures can be understood through their *coercive*, *mimetic* and *normative* effects. That is, organizations may adopt a specific system/process if it is *coerced* by either an organization on which it depends, or the larger society it operates within (Pfeffer & Salancik, 2003). It may also adopt the system/process by *mimicking* other successful organizations which have already adopted it (Mansfield, 1961); or by following the industry’s *norms*, standards and regulations (J. Taylor & Levitt, 2005) which clearly favour the new system/process.

These diffusion models, patterns, and pressures have been shown to collectively describe and help predict the incremental diffusion of technological solutions across a population. However BIM is not solely an innovative technological solution proliferating incrementally across the construction industry (Fox & Hietanen, 2007) (Mutai, 2009) (Gu & London, 2010) but a an organizational and *systemic* innovation (J. E. Taylor & Levitt, 2004) of complementary technologies, processes and policies. While BIM may be initially classified as a *technical innovation* (Murphy & Wardleworth, 2014), it will need to be urgently reclassified - upon its transformative adoption by organizations - as an *organizational innovation* characterised by the “generation, acceptance, and implementation of new ideas, processes, products or services” (OECD, 2005; Thompson, 1965, p. 2).

As covered in depth in earlier research (Succar, Sher, & Williams, 2012) and briefly explored in the Figure 2, BIM adoption by an organization pass through three adoption points pertaining to three capability stages. Even if multiple organizations pass through the first Point of Adoption (PoA) separating pre-BIM status from minimum BIM capability (Stage 1), the spread of *modelling* practices among this population does not necessarily or automatically translate into a diffusion of multidisciplinary *collaboration* or interdisciplinary *integration* practices (Stage 2 and 3 respectively). Similarly, BIM is not a mere technological solution but reflects a combinatory and mutational diffusion of technologies, workflows and protocols (Merschbrock & Munkvold, 2014) (Yoo, Richard J. Boland, Lyytinen, & Majchrzak, 2012). This multi-stage, multi-component nature of BIM – resembling a *complex adaptive system* (Johnson, 2002) - prevents the effortless application of technology-centric diffusion modelling and invites the development of more representative BIM adoption models.

1.5. Diffusion modelling and adoption models

This paper differentiates between ‘diffusion modelling’ and ‘adoption models’. Diffusion modelling uses mathematical means to understand the “patterns innovations follow as they spread across a population of potential adopters over time” (Fichman & Kemerer, 1999, p. 256). It serves in understanding the social forces underlying technology diffusion (Brancheau & Wetherbe, 1990); predicting the diffusion of products across a market (Mahajan, Muller, & Bass, 1990a); describing the time/speed of cumulative adoption of a specific innovation (Gurbaxani, 1990); deciphering why some innovations are ‘imitated faster’ in some markets (Mansfield, 1993); or establishing the impact regulation has on innovation diffusion (J. Taylor & Levitt, 2005).

Adoption models are conceptual structures describing how adoption – a term overlaying the definitions of implementation and diffusion – occurs across a population of organizations. Adoption models do not employ mathematical formulae to *explain past* or *predict future* diffusion patterns but use inductive inference to generate graphical representations that reduce topic complexity and promote understanding (Michalski, 1987). Each adoption model is formulated through a process of identification, classification and clustering, which simplify a large system by decomposing it into smaller sub-systems (Michalski & Stepp, 1987). From a utilitarian perspective, adoption models provide a set of tools to assess and develop policies which encourage implementation and facilitate diffusion.

Before introducing five macro BIM adoption models, the next section clarifies the research methodology underlying their development.

2. Research methodology

This article is built-upon and further extends the BIM Framework (Succar, 2009) by employing existing conceptual constructs – terms, classifications, taxonomies, models and frameworks - to identify, explain and test new constructs. This cumulative theory-building exercise is summarised in the BIM Framework Conceptual Reactor (Figure 3) incorporating the Normal Research Cycle by J. Meredith (1993) :

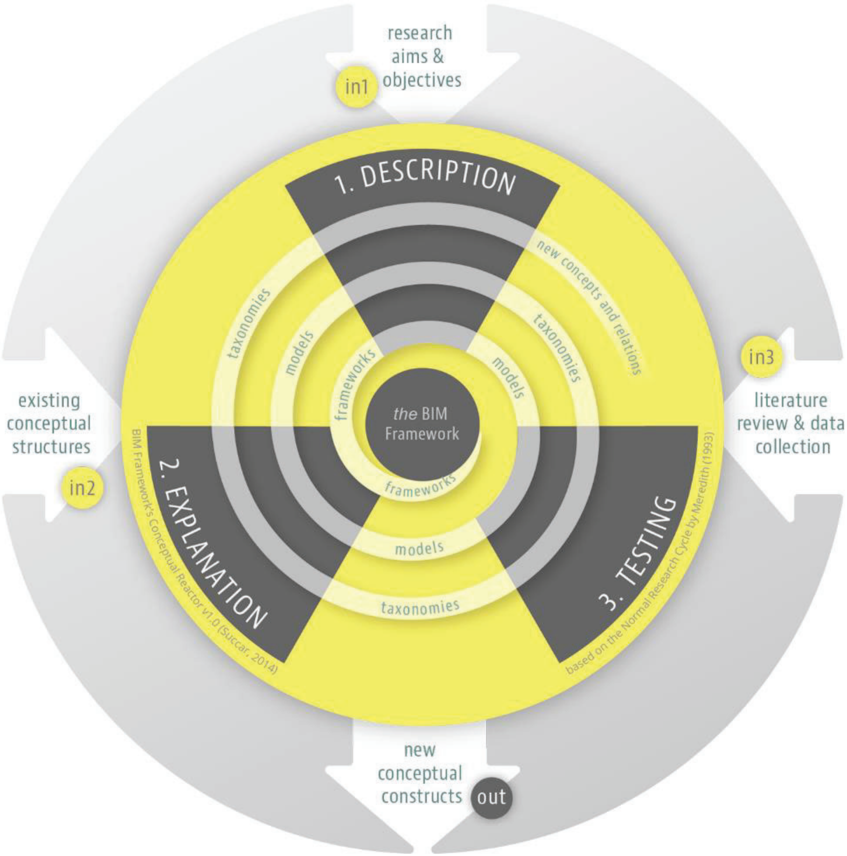

Figure 3. The BIM Framework Conceptual Reactor *v1.0* (full size, current version)

The conceptual reactor (Figure 3) represents how the BIM framework can be continuously extended according to evolved research aims and objectives (input 1). By integrating existing conceptual structures (input 2) with new knowledge gained through literature reviews, and data collection (input 3), the reactor can then generate new conceptual structures (output) after passing through an iterative, three-stage theory-building process. This process has been identified by J. Meredith (1993) (J. R. Meredith, Raturi, Amoako-Gyampah, & Kaplan, 1989) and includes three repetitive stages - description, explanation and testing:

First, the *description stage* develops a description of reality; identifies phenomena; explores events; and documents findings and behaviours. According to Dubin (1978, p. 85), “the more adequate the description, the greater is the likelihood that the units derived from the description will be useful in subsequent theory building.” Second, the *explanation stage* builds upon descriptions to *infer* a concept, a conceptual relationship or a construct; and then, develops a framework or a theory to explain and/or predict behaviours or events. In essence, the *explaining stage* develops a testable theoretical proposition which clarifies what has previously been described. Third, the *testing stage* inspects explanations and propositions for validity; tests concepts or their relationships for accuracy; and tests predictions against new observables.

Each macro BIM adoption model, presented in this paper, follows a similar cyclical path to that described by J. Meredith (1993) - from describing; to explaining; to testing; and then back to describing. First, a *description* of each macro BIM adoption model is generated through a process of inductive inference (Michalski, 1987), conceptual clustering (Michalski & Stepp, 1987) and reflective learning (Van der Heijden & Eden, 1998) (Walker, Bourne, & Shelley, 2008). Second, conceptual models are developed to visually *explain* the knowledge structures. Third, each model is *tested* through either a focus group, peer-review or questionnaire.

The conceptual reactor with its core three-stage approach reflects the researchers' underlying retroductive research strategy which follows a similar three-step approach. First, "the research starts in the domain of actual, by observing connections between phenomena […]. To do so, as a second step, researchers build a hypothetical model, involving structures and causal powers located in the domain of real, which, if it were to exist and act in the postulated way, would provide a causal explanation of the phenomena in question. The third step is to subject the postulated explanation to empirical scrutiny" (Leca & Naccache, 2006, p. 635). This *retroductive* research strategy represents a "logic of enquiry associated with the philosophical approach of Scientific Realism" Blaikie (2000, p. 108). Similar to deductive research, retroduction "starts with an observed regularity but seeks a different type of explanation". Through retroduction, events are explained *by postulating and identifying structures and causal powers capable of generating them* (Sayer, 1992); and by locating the "real underlying structure or mechanism that is responsible for producing the observed regularity" (Blaikie, 2000, p. 25). Retroduction uses "creative imagination and analogy to work back from data to an explanation" and involves the "building of hypothetical models as a way of uncovering the real structures and mechanisms which are assumed to produce empirical phenomena" (Blaikie, 2000, p. 25). In constructing these hypothetical models, ideas are "borrowed from known structures and mechanisms in other fields" (Atkinson, 2011, p. 2).

Models are clarity-improvement tools. By generating diffusion models, this paper thus introduces an *artificial reconstruction of reality* (J. R. Meredith et al., 1989, p. 307), a hypothesis to be used in assessing and comparing BIM implementation/diffusion across countries.

2.1. Built-in research limitations

BIM implementation and diffusion can be analysed across varied organizational scales. In previous papers (Succar, 2010b) (Succar, 2010a), we have identified twelve *organizational scales* (OScales) spread across three *organizational clusters*. These scales and clusters are intended to balance the dual notions of *flexibility,* to cater for the uniqueness of each OScale; and *uniformity,* to cater for the similarity between them. The *Macro cluster* includes market subdivisions, sectors, industries and specialities (OScales 1-7); the *Meso cluster* includes project-centric organizational teams (OScale 8); and the *Micro cluster* includes organizational subdivisions, groups, and individuals (OScale 9-12). Although the models proposed are applicable at a number of organizational scales, the focus of this paper is exclusively on BIM adoption at the macro cluster, and specifically at OScale 3 (defined markets or countries).

3. New Model List

After clarifying the terminology used in this research, and identifying the methodology adopted in generating new conceptual constructs, this section introduces five macro BIM adoption models (Table 1):

	ADOPTION MODEL TITLE	**ACCOMPANYING MATRIX OR CHART**	**INTENDED USE + APPLICABLE ORGANIZATIONAL SCALES** (OScales)
A	Diffusion Areas *model* (Figure 4)	Diffusion Areas *matrix* (Table 2) + Diffusion Areas *sample chart* (Figure 5)	Establish the diffusion areas to be assessed *[Applicable at OScales 1-10]*
B	Macro Maturity Components *model* (Figure 6)	Macro Maturity *matrix* (Table 11)	Assess the BIM maturity of countries holistically using a comparative matrix or granularly using component-specific metrics *[Applicable at OScales 1-7]*
C	Macro Diffusion Dynamics *model* (Figure 7)	Macro Diffusion Dynamics *matrix* (Table 12)	Assess and compare the directional pressures and mechanisms affecting how diffusion unfolds within a population *[Applicable at OScales 1-7; another version at OScales 9-12]*
D	Policy Actions *model* (Figure 8)	Policy Actions *matrix* (Table 13) + Policy Action Patterns *sample chart* (Figure 9)	Identify, assess and compare the actions policy makers take (or can take) to facilitate market-wide adoption *[Applicable across all OScales]*
E	Macro Diffusion Responsibilities *model* (Figure 10)	Macro Diffusion Responsibilities *matrix* (Table 14)	Assess and compare the roles played by different stakeholder groups in facilitating diffusion within and across markets *[Applicable at OScales 1-7; another version at OScales 9-12]*

Table 1. Macro BIM Adoption models, matrices and charts

3.1. Model A: diffusion areas

This macro adoption model clarifies how BIM *field types* (technology, process and policy) interact with BIM *capability stages* (modelling, collaboration and integration) to generate nine areas for targeted BIM diffusion analysis and BIM diffusion planning (Figure 4):

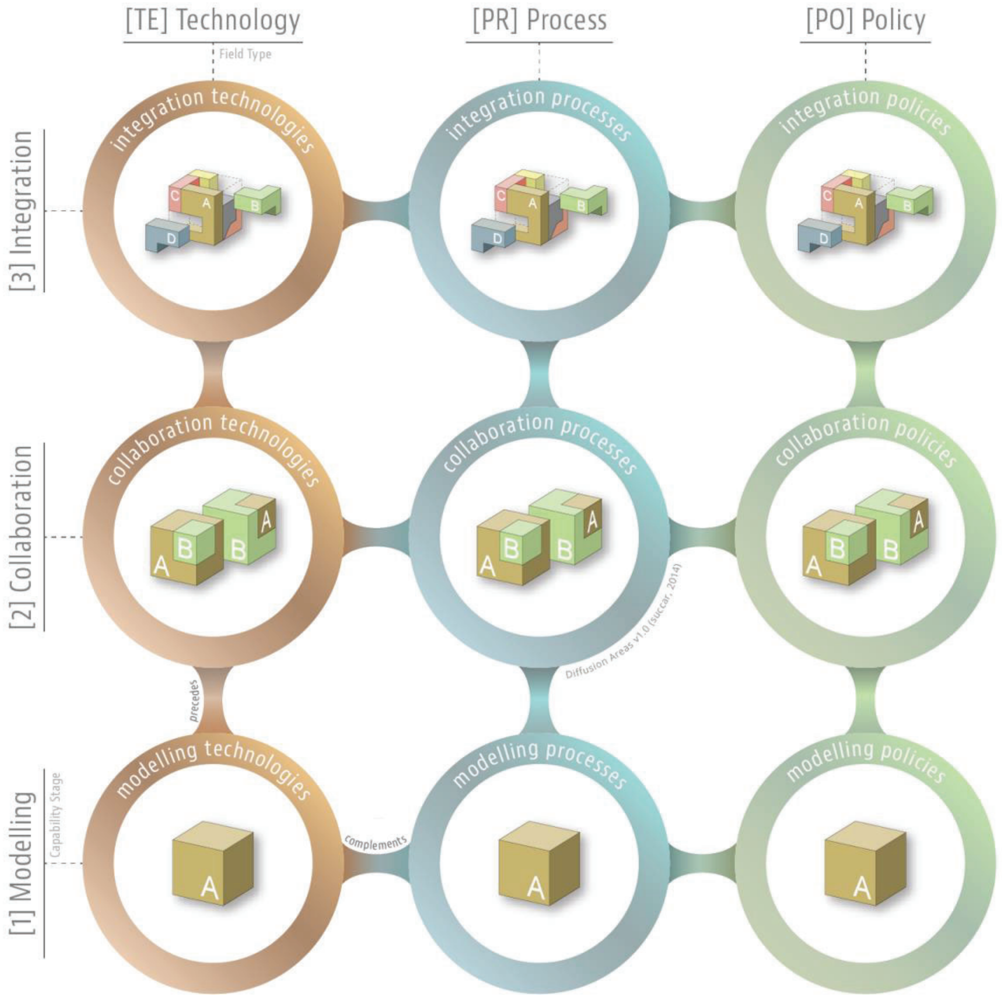

Figure 4. Diffusion Areas *model v1.0* (full size, current version)

The nine diffusion areas, explored in Table 2, can be assessed independently or collectively. For example, the diffusion of BIM software tools within a population (modelling technologies [1TE]) can be assessed separately, and using different assessment methods, than establishing the proliferation of *integrated project delivery* contracts (integration policies [3PO]). Also, the diffusion of multidisciplinary BIM educational curricula (collaboration policies [2PO]) can be assessed separately, or in combination with, the proliferation of collaborative BIM roles and responsibilities (collaboration processes [2PR]).

Cumulative Capability Increase →	TECHNOLOGY	PROCESS	POLICY
INTEGRATION	**3TE**: Integration Technologies Rate of adoption of *network-based* interchange solutions (e.g. model servers); the proliferation of real-time network-based integration across disparate systems	**3PR**: Integration Processes Rate of adoption of *integrated supply-chain* processes across the whole supply chain; the proliferation of interdisciplinary workflows across all project life cycle phases	**3PO**: Integration Policies Rate of adoption of *integrated supply-chain* standards, protocols and contractual agreements; the proliferation of interdisciplinary educational programmes
COLLABORATION	**2TE**: Collaboration Technologies Rate of *inter-organizational* adoption of model-sharing software and middleware tools (e.g. Navisworks, Vico and Ecodomus)	**2PR**: Collaboration Processes Rate of *inter-organizational* adoption of project BIM roles (e.g. Information Manager); the proliferation of multidisciplinary model-based workflows	**2PO**: Collaboration Policies Rate of *inter-organizational* adoption of modelling standards and collaboration protocols; the proliferation of collaboration-centric contractual agreements and educational programmes
MODELLING	**1TE**: Modelling Technologies Rate of *intra-organizational* adoption of BIM software tools (e.g. Revit and Tekla) and their underlying hardware and network requirements	**1PR**: Modelling Processes Rate of *intra-organizational* BIM roles (e.g. model manager, and BIM trainer) and model-based workflows	**1PO**: Modelling Policies Rate of *intra-organizational* adoption of modelling standards (e.g. naming standards, shared parameters, level of details, and property sets) and file exchange protocols

Table 2. Diffusion Areas *matrix*

The nine diffusion areas, their structured subdivisions and combinations, provide an opportunity for granular assessments of BIM diffusion within a population of adopters. Rather than being treated uniformly as a single set of data, or separated into disparate topics without an underlying conceptual structure, the Diffusion Areas' model (Figure 4) allows the generation of targeted ratings for comparative market analysis - as exemplified in Figure 5:

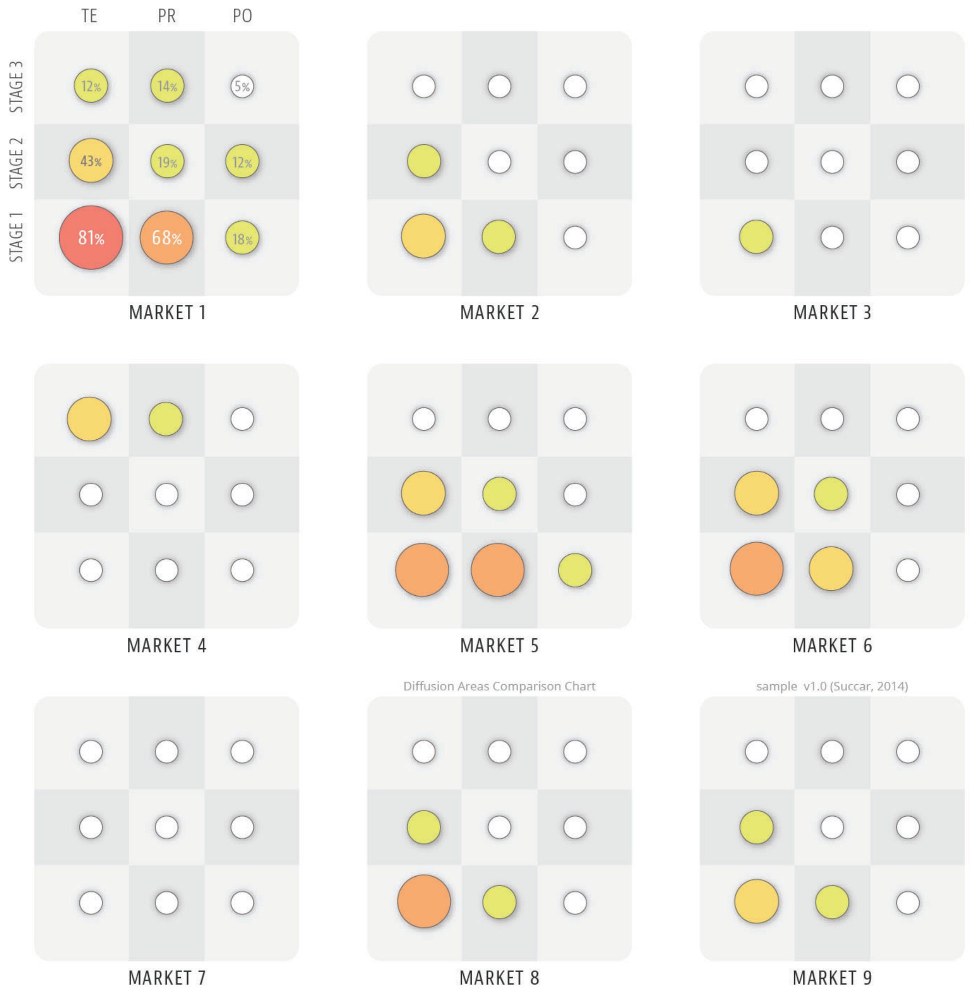

Figure 5. Diffusion Areas Comparison *sample chart v1.0* (full size, current version)

3.2. Model B: macro maturity components

The *macro maturity components* model identifies eight complementary components for measuring and establishing the BIM maturity of countries and other macro organizational scales: Objectives, stages and milestones; Champions and drivers; Regulatory framework; Noteworthy publications; Learning and education; Measurements and benchmarks; Standardised parts and deliverables; and Technology infrastructure (Figure 6):

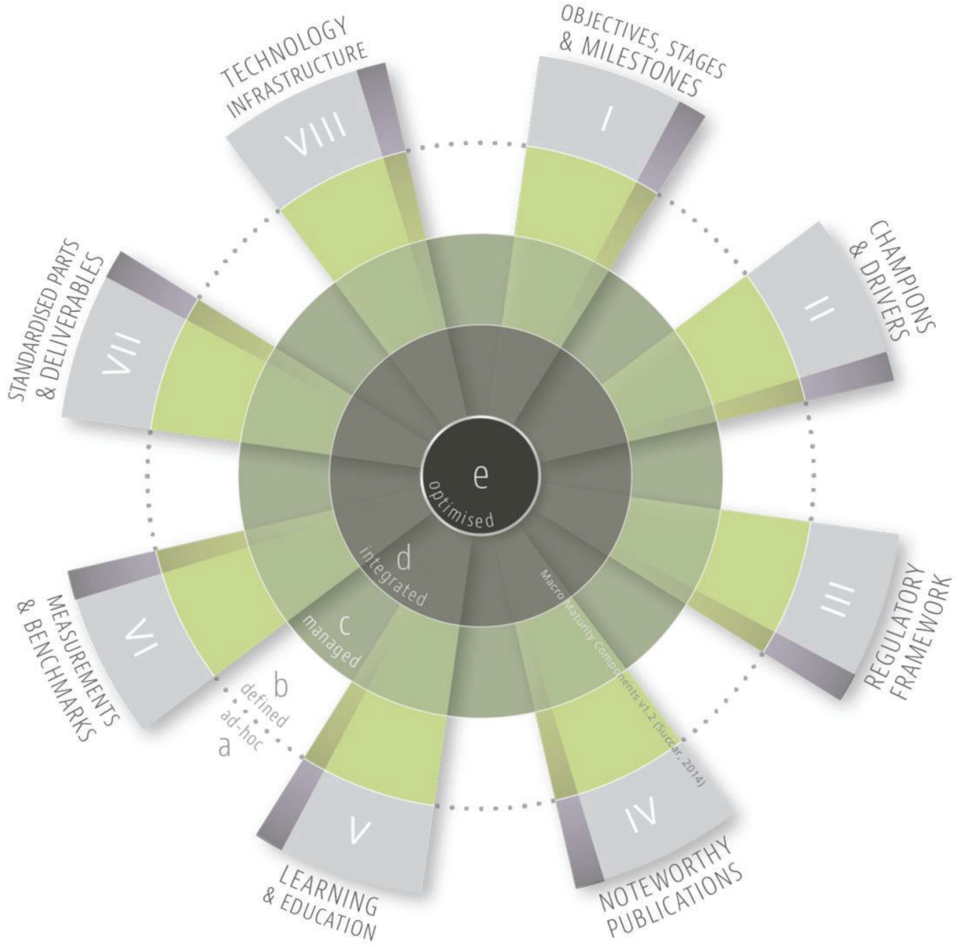

Figure 6. The Macro Maturity Components *model* v1.2[5] (full size, current version)

Macro maturity components are assessed using the BIM Maturity Index (BIMMI) which includes five maturity levels: [a] Ad-hoc or *low maturity*; [b] Defined or *medium-low maturity*; [c] Managed or *medium maturity*; [d] Integrated or *medium-high maturity*; and [e] Optimised or *high maturity* (Succar, 2010b). When applying the BIMMI, assessments can be made *holistically* (low detail 'discovery' assessments) or *granularly* (higher detail 'evaluation' assessment). 'Discovery' assessments are beneficial for comparing the relative maturity of each macro component against the other seven components - as represented by the Macro Maturity Matrix (Table 11); while 'evaluation' assessments allow the detailed analysis of each component using specialised metrics only applicable to that component. Below is explanation of the eight macro maturity components including sample granular component-specific metrics (Table 3 - Table 10):

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[5] This model was first published as Item 26 on the BIM Framework blog - July 20, 2014

I: Objectives, stages and milestones

This component represents the availability of clear BIM-specific policy objectives, intermediate capability stages, and measureable maturity milestones separating current status from a quantifiable future target. BIM policy objectives, stages and milestones may exist separately or found embedded within a country's wider construction strategy. For the purposes of macro maturity assessment, more-granular metrics can be used to evaluate objectives within their respective contexts, analyse the clarity of pre-determined stages, and compare the duration/effort separating different milestones (Table 3):

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
There are no capability stages separating *lack of ability* from heightened proficiency	Capability stages are defined yet lack internal consistency or well-defined boundaries (overlap with each other)	Capability stages are well-defined and consistent yet are not integrated with objectives and milestones	Capability stages are integrated with objectives and milestones	Capability stages are dynamically optimised in response to changes in other macro maturity components

Other granular metrics include: *The Availability of Long-term Objectives to Guide Market Adoption; The Availability of Maturity Milestones to Guide Market Adoption; …*

Table 3. *Availability of Capability Stages to Guide Market Adoption* metric

II: Champions and drivers

This component represents the individuals, groups and organizations undertaking the task of *demonstrating the efficacy of* an innovative system/process to a population of potential adopters. As early adopters (Rogers, 1995), champions can be individuals promoting a new software solution; a community of practice promoting a new process; or an industry association promoting a new standard. While champions are 'volunteer experimentalists', drivers are 'designated executors' of a top-down strategy (refer to Figure 7) with a mandate to stimulate the adoption of a designated technology, process or policy. Drivers may be individuals, groups, institutions or an authority intent on communicating, encouraging and monitoring the adoption of a system/process (refer to Figure 8).

The positive impacts of champions/drivers on innovation have been explored in numerous studies (Bossink, 2004; Howell & Higgins, 1990; Nam & Tatum, 1997; E. M. Rogers, 1995) especially if they exhibit *clustering* and *reach* characteristics (Schilling & Phelps, 2007). For the purposes of macro maturity assessment, the availability of champions/drivers within a market signals higher maturity when compared to markets lacking champions/drivers, or where champions/drivers do not exhibit clustering and reach characteristics. Additional granular metrics can be used to evaluate the competency of individual drivers (Succar, Sher, & Williams, 2013) or the championship/leadership style across markets (Table 4):

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
There is no designated policy driver; market may include volunteer champions	There is a designated policy driver; driver may not be influential or is not supported by a clear mandate	The designated driver is influential with a clear wide-reaching mandate	Designated driver's activities are integrated with other macro components	Driver's role no longer required due to system/process infusion across the market

Other granular metrics include: *Driver Influence; Driver Mandate Clarity; Driver Competency; Leadership Style; …*

Table 4. *Availability of a Policy Driver* metric

III: Regulatory framework

This component describes the contractual environment, intellectual property rights, and professional indemnity insurance underlying collaborative BIM projects. Information-rich, model-based deliverables require more detailed contractual, project and process management protocols than their pre-BIM counterparts. Responsibilities pertaining to shared models (e.g. elemental authorship and model ownership), collaborative processes (e.g. overlapping project phases and early involvement of subcontractors), and prescriptive protocols (e.g. data exchange structures and information delivery standards) add layers of complexity to team interactions. This complexity and varied risk environment can be mitigated by the availability of a regulatory framework clarifying the rights, responsibilities and liabilities of varied project stakeholders across overlapping – and even concurrent – project lifecycle phases.

For the purposes of macro maturity assessment, the availability of a regulatory framework - addressing procurement, workflows, deliverables, and stakeholder rights - signals higher maturity. More-granular metrics can be used to evaluate the proliferation of these sub-components across markets (Table 5):

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
Procurement policies do not include any requirements for digital workflows or model-based deliverables	Procurement policies include basic requirements for digital workflows and model-based deliverables	Procurement policies include detailed requirements for digital workflows and model-based deliverables	Model-based deliverables and digital workflows are integrated into all procurement policies	Procurement policies are continuously optimised to reflect industry best practices for model-based deliverables and digital workflows
Other granular metrics include: *Contractual Coverage of Digital workflows and Model-based deliverables; Extent of Handover Protocols for Information-Rich Models; Proliferation of Integrated Project Delivery; …*				

Table 5. Procurement Policy *metric*

IV: Noteworthy publications

This component represents publically-available documents of relevance, developed by influential industry stakeholders, and intended for a market-wide audience. As covered in detail in Kassem et al. (2013) (Succar, 2013a), noteworthy BIM publications (NBP)s pertain to three *knowledge content clusters* (guides, protocols and mandates) and eighteen *knowledge content labels* (e.g. report, manual, and contract). For the purposes of macro maturity assessment, this component clarifies the *availability of noteworthy BIM publications* within a specific market as a sign of maturity. Additional metrics can be used to evaluate the *distribution* of NBPs according to knowledge clusters/labels or the relevance of each NBP when compared to similar publications from other markets (Table 6):

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
The noteworthy publication includes out-dated information which is no longer usable or useful	The noteworthy publication is relevant, current and contains actionable information	The noteworthy publication is highly-relevant, well-cited and well-used in comparison to other similar-topic NBPs	The noteworthy publication is authoritative and impactful and considered a reference (among other references)	The noteworthy publication is the most authoritative document covering a specific topic
Other granular metrics include: *Distribution of Noteworthy Publications according to Knowledge Clusters and Labels; …*				

Table 6. Noteworthy Publications Relevance *metric*

V: Learning and education

This component represents market-wide educational activities covering BIM concepts, tools and workflows. These educational activities are either delivered through tertiary education, vocational training or professional development; as competency-based or course-based learning models (Voorhees, 2001) (Succar & Sher, 2013).

For the purposes of macro maturity assessment, this component clarifies whether digital workflows and model-based deliverables are included as learning topics within education/training programs. Additional metrics can be used to evaluate how BIM concepts, tools and workflows are infused into curricula (HEA, 2013, p. 8); if varied learning requirements of professionals, paraprofessionals and tradespeople are met (AIA-CA, 2012); and whether these learning/education resources are affordable and accessible (Table 7):

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
BIM is not included in the curricula	BIM is taught in separate learning unit(s) or introduced into existing units without altering their *formal* (pre-set) delivery structures or pre-BIM learning objectives	Unit structure(s) and learning objectives are formally altered to accommodate BIM tools, workflows and deliverables	Unit structure(s) and learning objectives are integrated with and complementary to all other BIM-infused units	BIM tools and workflows are inseparable from the unit's structure and learning objectives
Other granular metrics include: *Multi-disciplinary Integration of Curricula; Use of Simulated Design, Construction and Operation Environments; Expertise of Learning Providers; …*				

Table 7. BIM Infusion into Tertiary Curricula *metric*

VI: Measurements and benchmarks

This component represents market-wide metrics for benchmarking project outcomes and assessing the capabilities of individuals, organizations and teams. The availability of market-specific – or the formal adoption of international - benchmarks and metrics signifies a market's ability to assess and potentially improve its performance. Additional granular metrics are proposed in Table 8:

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
There are no common or mandated project performance benchmarks	Project performance benchmarks are defined/agreed by industry associations or mandated by regulatory bodies	Project performance benchmarks are centrally collated and accessed by stakeholders	Project performance benchmarks are integrated with other organizational and team benchmarks	Project performance benchmarks are continuously optimised to reflect emergent technologies, workflows and protocols
Other granular metrics include: *Organizational Capability Benchmarks; Individual Competency Benchmarks; …*				

Table 8. Project Performance Benchmark *metric*

VII: Standardised parts and deliverables

This component represents the *standardised, data-rich model parts*[6] (e.g. walls, beams, HVAC units, doors and furniture) which populate object-based models. It also represents *model uses*[7], the standardisable deliverables from generating, collaborating-on and linking object-based models to external databases. For the purposes of macro maturity assessment, the availability of standardised parts and deliverables signals a mature market. Additional granular metrics are proposed in Table 9:

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
There are no market-specific elemental classification system	There is a number of market-specific elemental classification system	A unified elemental classification system is standardised and centrally managed by a dedicated authority	The standardised elemental classification system is integrated with software tools and specification/costing regimes	The standardised elemental classification system is continuously reviewed and optimised to reflect international best practices
Other granular metrics include: *Availability of National Object Libraries; Availability of Standardised Model Uses; …*				

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[6] Also typically referred to as elements, components, objects or families.

[7] Model uses can be specific to the *design phase* (e.g. immersive environments), *construction phase* (e.g. construction logistics and flow), *operation phase* (e.g. asset tracking), or across all *project lifecycle phases* (e.g. cost-planning and lean modelling)

Table 9. Availability of an Elemental Classification System *metric*

VIII: Technology infrastructure

This component refers to the availability, accessibility and affordability of hardware, software and network systems (CID, 2014). It also refers to the availability, usability, connectivity and openness of information systems hosting data-rich three-dimensional models. Additional granular metrics are proposed in Table 10:

a *(low)*	**b** *(medium-low)*	**c** *(medium)*	**d** *(medium-high)*	**e** *(high)*
There is no central repository for data-rich 3D models	There is an optional or feature-poor central repository for data-rich 3D models	There is a central and mature system for submitting and querying data-rich 3D models	The central model repository is integrated with multiple data sources, infrastructure models, procurement systems, first responders and the internet of things (IoT)	The central model repository is continuously optimised to improve stakeholder accessibility and allow innovative uses
Other granular metrics include: *Data Openness Requirements; Availability of E-submission Systems; Software Availability and Affordability; …*				

Table 10. Central Model Repository *metric*

Macro maturity matrix

The macro maturity matrix (Table 11) provides a summary of the eight macro maturity components (Figure 6) mapped against the five level of the BIM maturity index:

		a low maturity	**b** medium-low maturity	**c** medium maturity	**d** medium-high maturity	**e** high-maturity
I	**Objectives, stages and milestones**	There are no market-scale BIM objectives or well-defined BIM implementation stages or milestones	There are well-defined macro BIM objectives, implementation milestones and capability stages	BIM objectives, stages and milestones are centrally managed and formally monitored	BIM objectives and stages are integrated into policies, processes and technologies and manifest themselves within all other macro maturity components	BIM objectives and stages are continuously refined to reflect advancement in technology; facilitate process innovation; and benefit from international best practices
II	**Champions and drivers**	There are no identifiable market-wide champions or BIM implementation drivers	There are one or more volunteer champions and/or informal BIM drivers operating across the market	There is a unified task group or committee driving BIM implementation/diffusion across the market	Driver(s) coordinate all macro adoption activities, minimise activity overlaps, and address diffusion gaps	Driver(s) role is diminished, replaced by optimised systems, standards and protocols
III	**Regulatory framework**	There is no formal BIM-era regulatory framework	There is a formal regulatory framework addressing basic BIM-era rights and responsibilities of a number of stakeholders	The formal regulatory framework covers all BIM-era rights and responsibilities of all stakeholders	The regulatory framework is integrated into all requirements, roles, processes and deliverables	The regulatory framework is continuously refined to reflect technological advancements and optimised collaborative workflows
IV	**Noteworthy publications**	There are no - or a small number of - noteworthy BIM publications (NBPs) across the market	There are many NBPs with overlapping knowledge content; some NBPs are redundant or collectively include knowledge gaps	NBPs are developed and/or coordinated by a single entity thus minimising overlaps and knowledge gaps	NBPs are authoritative , interconnected and integrated across project life cycle phases and the whole construction supply chain	NBPs are continuously optimised to reflect international best practices
V	**Learning and education**	BIM learning topics are neither identified nor included within legacy education/training programs; learning providers lack the ability to deliver BIM-infused education	BIM learning topics are identified and introduced into education/training programs; BIM learning providers are available across a number of disciplines and specialties	BIM learning topics are mapped to current and emergent roles; BIM learning providers deliver accredited programs across disciplines and specialties	BIM learning topics are integrated across educational tiers (tertiary, and vocational) and address the learning requirements of all industry stakeholders	BIM learning topics are infused (not separately identifiable) into education, training and professional development programs
VI	**Measurements**	There are no market-wide	Formal metrics are used to	Standardised metrics are	Standardised metrics and	Standardised metrics are

		a low maturity	b medium-low maturity	c medium maturity	d medium-high maturity	e high-maturity
	and benchmarks	metrics applied in measuring BIM diffusion, organizational capability or project performance	benchmark project outcomes and assess the abilities of individuals, organizations and teams across the market	used to centrally benchmark project outcomes; certify the abilities of individuals, organizations and teams; and accredit learning programs, software systems and project delivery mechanisms	benchmarks are integrated into project requirements, workflows and deliverables; consistently used in defining and procuring services; and used to prequalify the abilities of individuals, organizations and teams	continuously revised to reflect evolving accreditation requirements and international best practices
VII	**Standardised parts and deliverables**	There no market-specific *object libraries* (e.g. doors and windows); service delivery *model uses* (e.g. clash detection) and *operational data* requirements (e.g. COBie)	*Object libraries* are available yet follow varied modelling and classification norms; service delivery *model uses* and *operational data* requirements are informally defined and partially used	Standardised *object libraries* are available and used; service delivery *model uses* and *operational data* requirements are formally defined and used across all project lifecycle phases	Standardised *object libraries*, service delivery *model uses,* and *operational data* requirements are integrated into, procurement mechanisms, project workflows and lifecycle facility operations	Standardised *object libraries*, service delivery *model uses* and *operational data* requirements are continuously optimised and realigned to improve usage, accessibility, interoperability and connectivity
VIII	**Technology infrastructure**	Non-existent, inadequate or unaffordable technology infrastructure (software, hardware and networks) as to prohibit widespread BIM adoption	The technology infrastructure is of adequate quality and affordability to enable BIM implementation within organizations and diffusion across varied market sectors	The technology infrastructure is of high quality and affordability enabling the efficient exchange, storage and management of complex, federated models among dispersed project teams	The technology infrastructure is uniformly accessible and interoperable allowing real-time network-based integration across disparate systems and data networks	The technology infrastructure is intuitive and ubiquitously accessible allowing seamless interchange between all users, virtual systems and physical objects across the whole lifecycle

Table 11. Macro Maturity Matrix at *Granularity Level 1*

The macro maturity matrix (Table 11) can be used in identifying the comparative BIM maturity across markets. The matrix aggregates a number of sub-topics within each component and is thus suitable for low-detail ‘discovery’ assessment (Granularity Level 1), where the contents of each cell represents - partially or fully - the current maturity status. More detailed ‘evaluation’ assessments (Granularity Level 2)[8] require the integration of a large number of metrics unique to each component (refer back to Table 3 - Table 10).

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[8] The varied applications of the four granularity levels and their applicability across organizational scales have been discussed in detail in Succar (2010b, Table 8).

3.3. Model C: macro diffusion dynamics

According to Geroski (2000, p. 621), “the real problem may not be understanding how the process of diffusion unfolds, but understanding how it starts”. To allow a clearer understanding of *from-where* and *how* a diffusion starts to unfold within a population, this macro adoption model identifies three *diffusion dynamics* – top-down, bottom-up and middle-out (Figure 7):

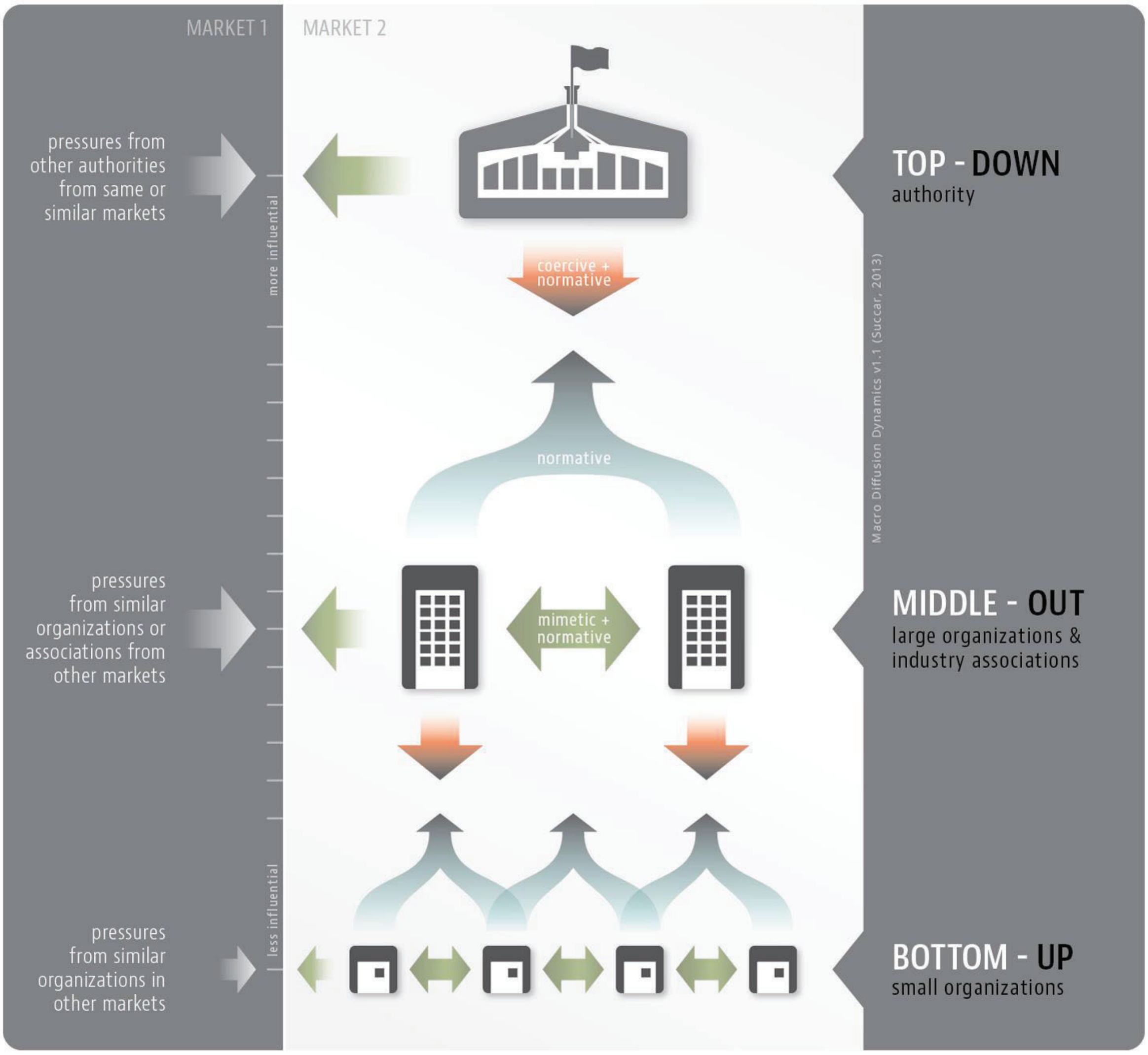

Figure 7. Macro Diffusion Dynamics *model*[9] *v1.1* (full size, current version)

The three diffusion dynamics introduced in Figure 7 embody *horizontal* and *vertical* mechanics, and a combination of isomorphic pressures - coercive, mimetic and normative – allowing innovation to contagiously pass from ‘transmitters’ to adopters (Strang, 1991) (DiMaggio & Powell, 1983) (Cao et al., 2014).

Horizontal mechanisms represent the mimetic effects organizations have on their peers; while vertical mechanisms represent the upward and downward pressures (normative and coercive) organizations have

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[9] An earlier version of this model was first published as Episode 19 on BIMThinkSpace.com - July 12, 2014

on non-peer organizations across the supply chain. These dynamics, mechanics and pressures are combined in Table 12:

DIFFUSION DYNAMIC	MACRO ACTOR, TRANSMITTER	PRESSURE MECHANISM	PRESSURE RECEPIENT, POTENTIAL ADOPTER	ISOMORPHIC PRESSURE TYPE
Top-Down	Government or regulatory body	Downwards	All stakeholders falling within the circle of influence of the authority exerting pressure	Coercive; normative
		Horizontal	Governments and authorities in other markets	mimetic
Middle-Out	Large organization or industry association	Downwards	Smaller organizations further down the supply chain; members of industry associations	Coercive; normative; mimetic
		Upwards	Governments and regulatory bodies within the market	Normative
		Horizontal	Other large organizations and industry bodies within or outside the market	Mimetic; normative
Bottom-Up	Small organization	Upwards	Larger organizations and industry bodies	Normative
		Horizontal	Other small organizations	Mimetic; normative

Table 12. Macro Diffusion Dynamics *matrix*

The three dynamics discussed in Table 12 identify the how the adoption decision taken by one player influences the adoption decisions of other players. For example, the early adoption of a policy player (an authority) of an innovative policy in one market encourages later adopters to make “the same choices as early adopters without having gone through the same investment in learning by experience” (Geroski, 2000, pp. 618-619) (Simmons & Elkins, 2004), a process often referred to as the ‘information cascade’ or ‘bandwagon effect’ (Geroski, 2000) (Mansfield, 1961). As explored by Simmons and Elkins (2004, p. 174), policy players of a specific market “pay deliberate attention to foreign models and their outcomes […as…] foreign models can encourage or expedite adoption by inserting a policy innovation on a legislature's agenda. A foreign model may also offer a ready-made answer to ill-defined domestic pressure for "change" and "innovation." Or it may legitimate conclusions or predispositions already held or add a decisive data point in the evaluation of alternatives (Bennett, 1991).” That is, the adoption of a BIM diffusion policy by one authority within a specific market may result – through mimetic and normative pressures - in the adoption of similar BIM diffusion policies by other authorities in different markets.

These top-down, bottom-up and middle-out dynamics are not independent: the diffusion of innovation at the lower-end of the supply chain (e.g. within smaller organizations) will lead to the development of a diffusion phenomenon at the macro-scale. Similarly, the diffusion of innovation at the higher-end of the supply chain will influence the behaviour of smaller organizations and individuals operating at the micro scales (Everett M Rogers et al., 2005, p. 13) (Johnson, 2002).

3.4. Model D: policy actions

Information provision by policy makers to a target population of potential adopters - highlighting the advantages of an innovative system/process - will not necessarily encourage implementation or speed-up diffusion (Stoneman & Diederen, 1994). However, policy makers may affect the adoption of an innovative solution through “a judicious mix of information provision and subsidies” (Geroski, 2000, p. 621).

This macro adoption model focuses on the actions a policy maker takes to influence the market-wide adoption of an innovative system/process. The Policy Actions model (Figure 8) identifies three implementation *activities* (communicate, engage, monitor) mapped against three implementation *approaches* (passive, active and assertive) to generate nine policy *actions*:

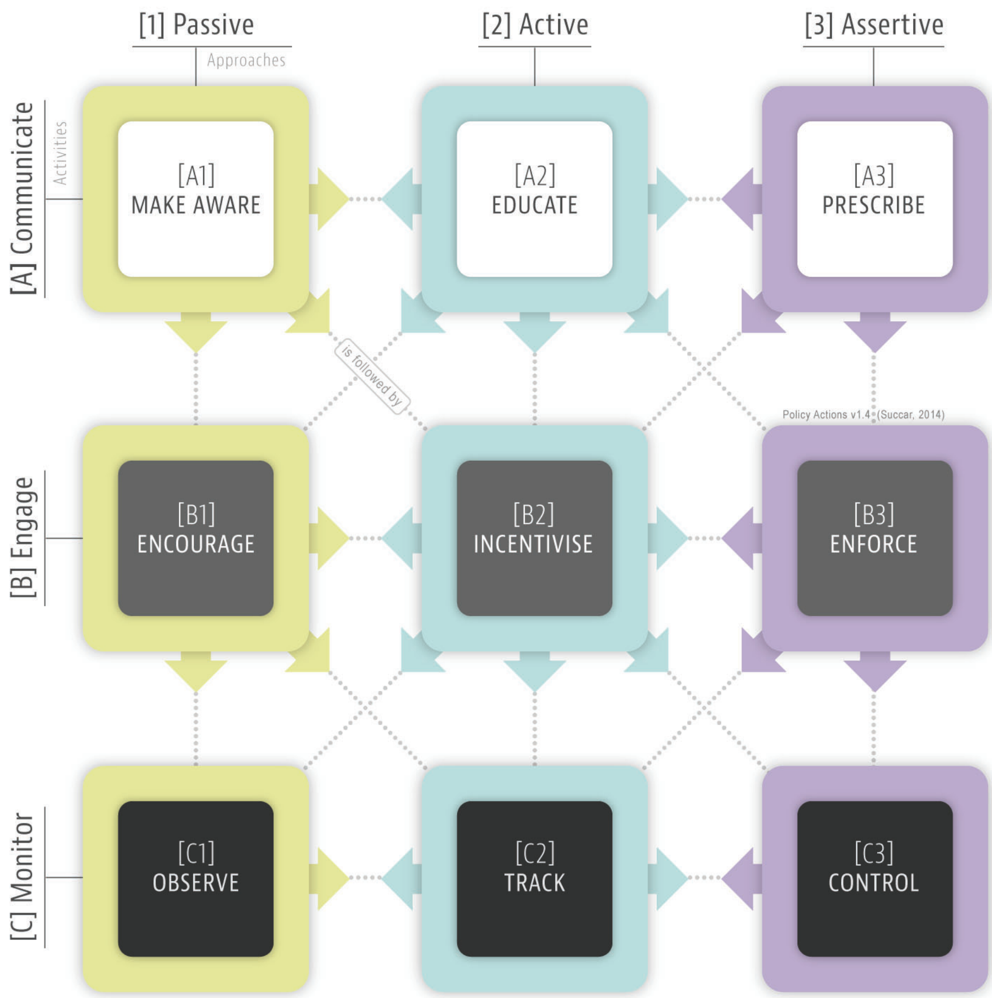

Figure 8. Policy Actions *model v1.4* (full size, current version)

The Policy Actions model (Figure 8) identifies nine actions (squares) and represents the relation between them (directional arrows and dotted connecting lines)[10]. The policy actions are briefly explained in Table 13:

APPROACHES

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[10] The Policy Implementation Actions model is a visually-enhanced ‘concept map’ with *concepts* represented as squares, *relations* represented as dotted lines, and textual *labels* clarifying the ontological relation between concepts (Tergan, 2003) (Hoffman & Lintern, 2006). That is, action A1 (Make Aware) *is followed by* either A2 (Educate), B1 (Encourage) or B2 (Incentivise). To disallow a counter-intuitive bottom-up use of this model, top-down and horizontal-diagonal arrows are added. For more information covering how concept maps are used to graphically represent BIM Framework parts, please refer to Succar (2009, p. 368).

		[1] PASSIVE	**[2] ACTIVE**	**[3] ASSERTIVE**
ACTIVITIES	**[A] COMMUNICATE**	**Make aware**: the policy player informs stakeholders of the importance, benefits and challenges of a system/process through formal and informal communications	**Educate**: the policy player generates informative guides to educate stakeholders of the specific deliverables, requirements and workflows of the system/process	**Prescribe**: the policy player details the exact system/process to be adopted by stakeholders
	[B] ENGAGE	**Encourage**: the policy player conducts workshops and networking events to encourage stakeholders to adopt the system/process	**Incentivise**: the policy player provides rewards, financial incentives and preferential treatment to stakeholders adopting the system/process	**Enforce**: the policy player includes (favours) or excludes (penalises) stakeholders based on their respective adoption of the system/process
	[C] MONITOR	**Observe**: the policy player observes as (or if) stakeholders have adopted the system/process	**Track**: the policy player surveys, tracks and scrutinizes how/if the system/process is adopted by stakeholders	**Control**: the policy player establishes financial triggers, compliance gates and mandatory standards for the prescribed system/process

Table 13. Policy Actions *matrix*

The three approaches within each activity signify an increase in the intensity of policy maker's involvement in facilitating BIM adoption, from a passive stance to more assertive actions. Also, the three activities signify a progression from clarifying the availability, benefit or necessity of a new system/process, to assessing adoption behaviours, challenges and outcomes. Each of the nine resulting policy actions can be further divided into smaller policy tasks. For example, the *incentivise action* [B2] can be subdivided into *incentivise tasks* – make tax regime favourable for BIM adoption, develop a BIM procurement policy, and introduce BIM-focused funding (Boya, Zhenqiang, & Zhanyong, 2014) – that can be undertaken by policy makers.

These activities, actions and tasks can be used as a *template* to structure a policy intervention, or as an *assessment tool* to compare policy actions across different countries (Figure 9):

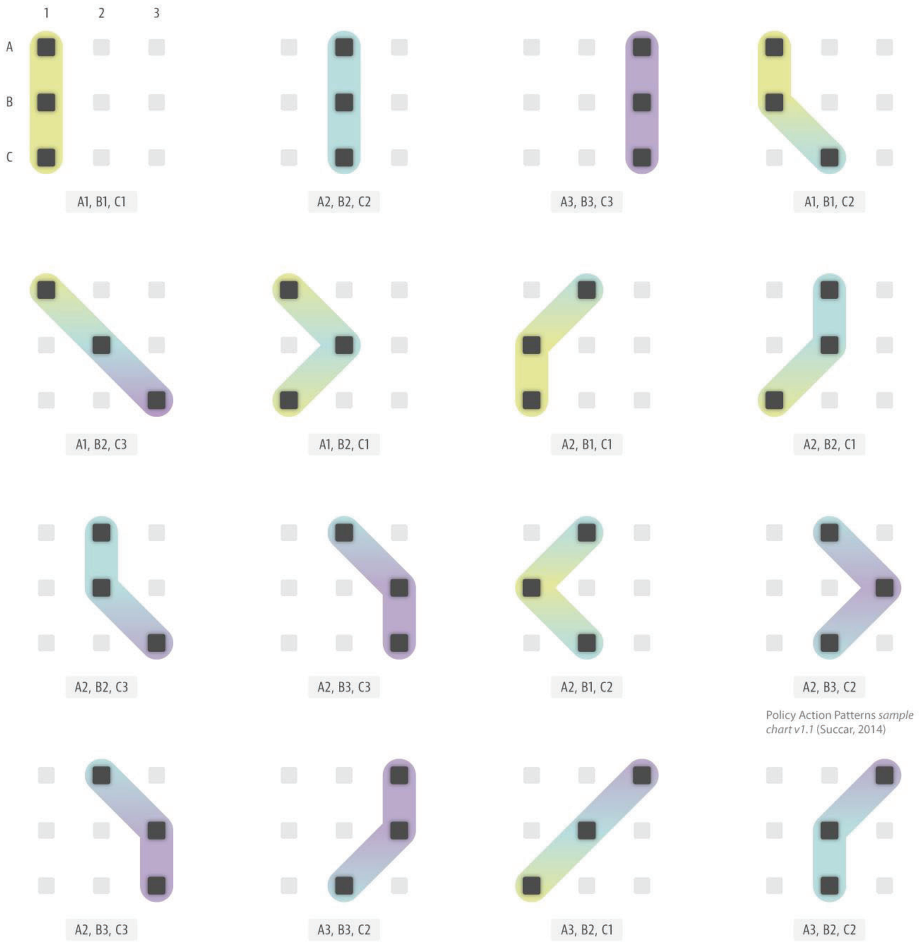

Figure 9. Policy Action Patterns *sample chart v1.1* (full size, current version)

The Policy Action Patterns sample chart (Figure 9) allows a quick comparison of diffusion actions undertaken by policy makers in different markets.

3.5. Model E: macro diffusion players

This macro adoption model (Figure 10) analyses BIM diffusion through the roles played by industry stakeholders as a network of actors (Linderoth, 2010). It first identifies nine *BIM player types* (stakeholders) distributed across three *BIM fields* (technology, process and policy) as defined within the BIM framework (Succar, 2009). The nine player types are: authorities, construction organizations, software developers, educational institutions, individuals, value-adding resellers, industry associations, communities of practice, and technology advocates:

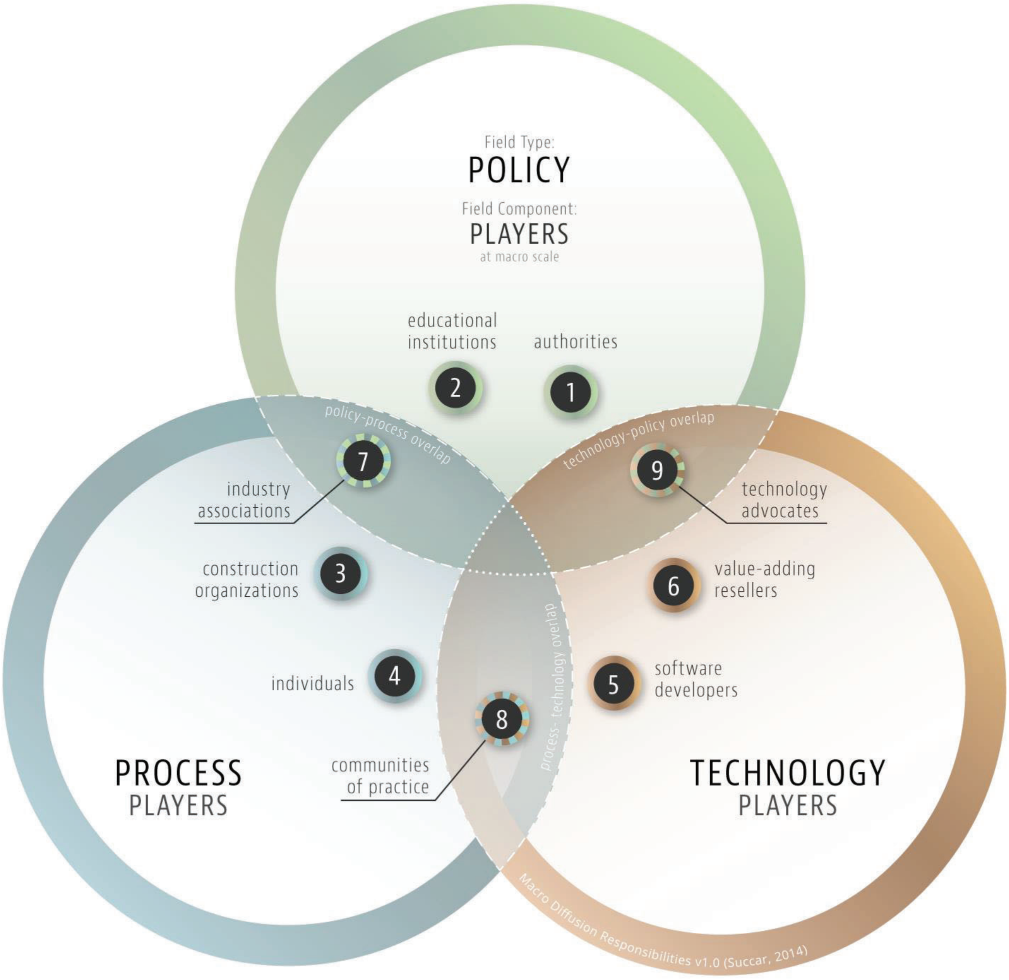

Figure 10. Macro Diffusion Responsibilities *model v1.0* (full size, current version)

The nine player types[11] belong to either BIM field or their overlaps. Table 14 provides a succinct description of each player type followed by how this subdivision can be used in evaluating BIM diffusion within and across different markets:

POLICY FIELD	PROCESS FIELD	TECHNOLOGY FIELD
1 Authorities Governmental players undertaking an active role in mandating or encouraging the adoption of BIM tools and workflows *e.g. the BIM Task Group in the UK and BCA in Singapore*	**3 Construction organizations** Designers, contractors, owners, operators and other organizational players involved in deploying BIM tools and workflows, training their staff and delivering BIM-enabled outcomes	**5 Software developers** The large software houses responsible for developing and maintaining BIM software tools, network solutions and middleware *e.g. Autodesk, Nemetschek and Trimble*
2 Educational institutions The universities and not-for-profit technical institutions developing and delivering learning programs and materials	**4 Individuals** The individual practitioner, researcher, lecturer and student involved in learning, or actively implementing BIM tools and workflows	**6 Value-adding resellers** The companies bridging and maintaining the relationship between software/network solution developers and end users
POLICY-PROCESS OVERLAP	PROCESS-TECHNOLOGY OVERLAP	POLICY-TECHNOLOGY OVERLAP
7 Industry associations Associations dedicated to representing the interests of their individual and organizational members *e.g. AMCA in Australia*	**8 Communities of practice** The informal grouping of individuals with a shared interest in improving their own BIM performance *e.g. Revit user groups*	**9 Technology advocates** The associations involved in developing and promoting technology-centric solutions for industry challenges *e.g. buildingSMART*

Table 14. Macro Diffusion Responsibilities *matrix*

Using this macro adoption model (Figure 10), a number of assessment activities can be conducted – including:

- Isolate BIM players by their group and analyse their BIM diffusion activities. An example assessment question would be: “What is the role played by Industry Association X in facilitating BIM diffusion within its membership base?”
- Compare the BIM diffusion activities of one player group to other groups within the same market. For example: “Which player group played a more leading BIM diffusion role in ‘Country A’: Education Institutions or Industry Associations?”
- Compare the BIM diffusion activities of players pertaining to the same group across different markets. For example: “Is the BIM diffusion role played by large contractors in ‘Country A’ similar to the role played by large contractors in ‘Country B’?”

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[11] Pending further research, the tenth player type at the intersection of the three fields is intentionally excluded from this model.

4. Conclusion

This paper introduced numerous new concepts, models and decision support tools for macro BIM adoption assessment and planning. It first presented a number of delineations between readiness, capability and maturity; between implementation and diffusion; and between diffusion modelling and adoption models. Second, it introduced the Point of Adoption (PoA) concept and linked it to previous BIM capability/ maturity research. Third, it clarified the research methodology, introduced the BIM Framework conceptual reactor, and discussed the research's underlying retroductive strategy. Fourth, it extended the BIM Framework by introducing five new adoption models, matrices and charts applicable across multiple organizational scales (Table 1): Model A identified nine areas for targeted BIM diffusion assessment and planning; Model B introduced eight components and a number of granular metrics for assessing and comparing the BIM maturity of countries; Model C identified three directional dynamics that clarify how diffusion unfolds within a market; Model D defined three activities, three approaches and nine actions for assessing, comparing and planning adoption policies across markets; and Model E defined nine groups to be used in analysing the diffusion activities/roles played by industry stakeholders.

Based on the above deliverables, this research – presented in two complementary papers - contributes to domain knowledge by:

- Setting the scene for macro BIM adoption assessment based on an established framework with a large set of interconnected terms, classifications, taxonomies and models;
- Refocusing the discussion away from software acquisition/implementation as a singular criterion for BIM diffusion surveys and studies;
- Overlaying the concepts of BIM implementation and BIM diffusion into a single term thus generating a unified view (Figure 2) for establishing and comparing the readiness, capability and maturity of organizations;
- Introducing five macro adoption models, their companion matrices and charts to be used in assessing and comparing BIM adoption across countries;
- Identifying multiple avenues for domain researchers to adapt, improve or correlate adoption models; each model represents a separate opportunity for data collection and additional conceptual investigation; and
- Informing the development of country-specific BIM implementation and diffusion strategies; policy makers can use these concepts and knowledge tools to either assess their ongoing BIM adoption efforts or to structure the development of new ones.

Research is currently being conducted to apply these concepts and tools across a number of countries. The results of these applications, and the conceptual calibrations that ensue, will be published in an upcoming paper. The deliverable of this research will instigate discussions among policy makers, encourage additional BIM implementation/diffusion research, and hopefully contribute to the improvement of BIM adoption policies across a number of markets.

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