ARTICLE

Measuring BIM performance: Five metrics

Bilal Succar*, Willy Sher and Anthony Williams

School of Architecture and Built Environment, University of Newcastle, Callaghan Campus, NSW 2308, Australia

Abstract

The term Building Information Modelling (BIM) refers to an expansive knowledge domain within the design, construction and operation (DCO) industry. The voluminous possibilities attributed to BIM represent an array of challenges that can be met through a systematic research and delivery framework spawning a set of performance assessment and improvement metrics. This article identifies five complementary components specifically developed to enable such assessment: (i) BIM capability stages representing transformational milestones along the implementation continuum; (ii) BIM maturity levels representing the quality, predictability and variability within BIM stages; (iii) BIM competencies representing incremental progressions towards and improvements within BIM stages; (iv) Organizational Scales representing the diversity of markets, disciplines and company sizes; and (v) Granularity Levels enabling highly targeted yet flexible performance analyses ranging from informal self-assessment to high-detail, formal organizational audits. This article explores these complementary components and positions them as a systematic method to understand BIM performance and to enable its assessment and improvement. A flowchart of the contents of this article is provided.

Keywords – Building Information Modelling; capability and maturity models; performance assessment and improvement

A BRIEF INTRODUCTION TO BUILDING INFORMATION MODELLING (BIM)

BIM is a term that is used by different authors in many different ways (Figure 1). The nuances between their definitions highlight the rapid growth the area has experienced, as well as the potential for confusion to arise when ill-defined terminology is used to communicate specific meanings. In the context of this article, BIM refers to a set of interacting *policies*, *processes* and *technologies* (illustrated in Figure 2) that generate a 'methodology to manage the essential building design and project data in digital format throughout the building's life-cycle' (Penttilä, 2006). It is important to identify the knowledge structures, internal dynamics and implementation requirements of BIM if confusion and duplication of effort are to be avoided.

SOME INDICATORS OF THE PROLIFERATION OF BIM

There are many signs that the use of BIM tools and processes is reaching a tipping point in some markets (Keller, Gerjets, Scheiter, & Garsoffky, 2006; McGraw-Hill, 2009). For example, in the USA an increasing number of large institutional clients now require object-based three-dimensional (3D) models to be provided as a part of tender submissions (Ollerenshaw, Aidman, & Kidd, 1997). Furthermore, the UK Cabinet Office has recently published a construction strategy article that requires the submission of a 'fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) as a minimum by 2016' (BIS, 2011; UKCO, 2011, p. 14). Other signs include the abundance of BIM-specific software tools, books, new media tools and reports (Eppler & Platts, 2009).

*Corresponding author: *E-mail*: bsuccar@changeagents.com.au

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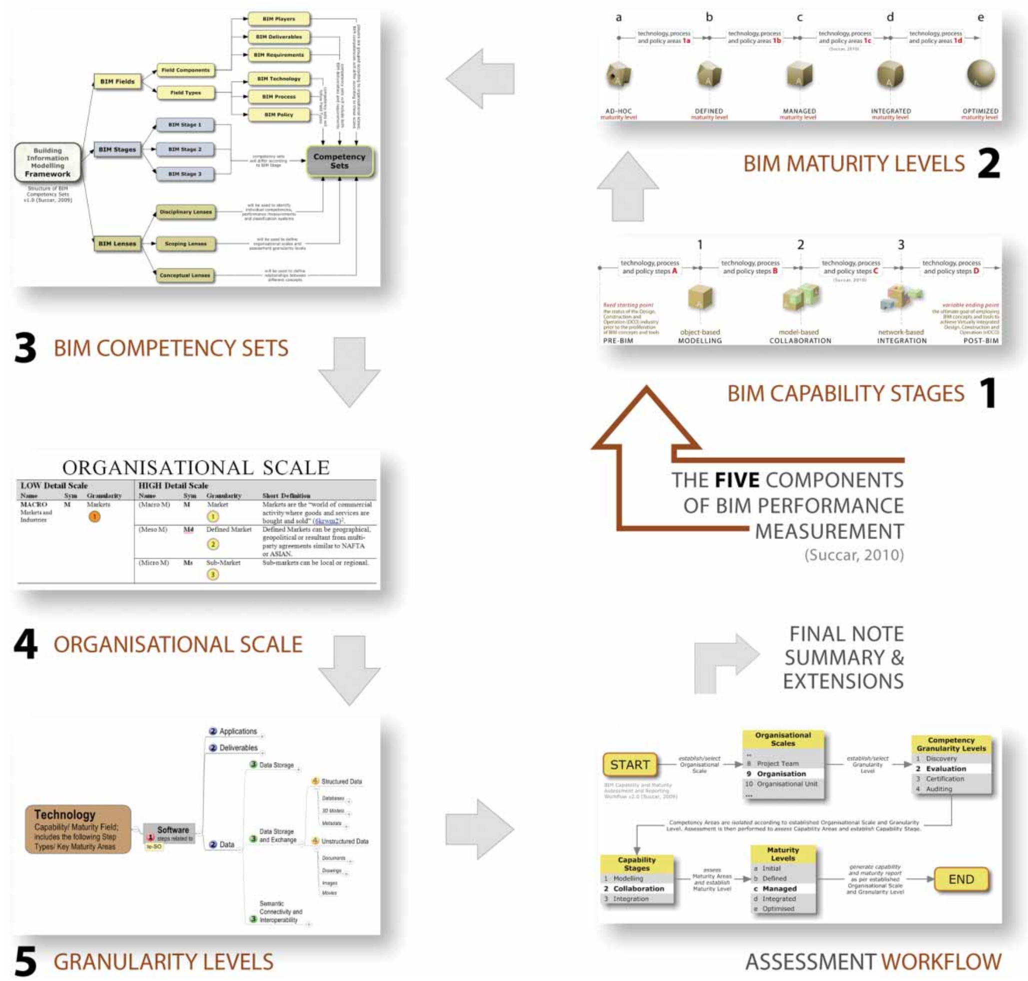


FIGURE 1 Flowchart of the contents of this article

ISSUES ARISING FROM THE PROLIFERATION OF BIM

Notwithstanding the much-touted benefits of BIM as a means of increasing productivity, there are currently few metrics that measure such improvements. Furthermore, little guidance is available for organizations wishing to *generate new* or *enhance* their *existing* BIM deliverables. Those wishing to adopt BIM or identify and/or prioritize their requirements are thus left to their own devices. The implementation of any new technology is fraught with challenges and BIM is no exception. In addition, those implementing BIM frequently expect to be able to realize significant benefits and productivity gains while they are still inexperienced users. Successful implementation of these systems requires an appreciation of how BIM resources (including hardware, software as well as the technical and management skills of staff) need to evolve in harmony with each other. The multiple and varied understandings that practitioners have of BIM further compound the difficulties they experience. When the unforeseen happens, the risks, costs and difficulties associated with implementing BIM increase. In such circumstances compromises are likely to be made leading, in turn, to users' expectations not being met.

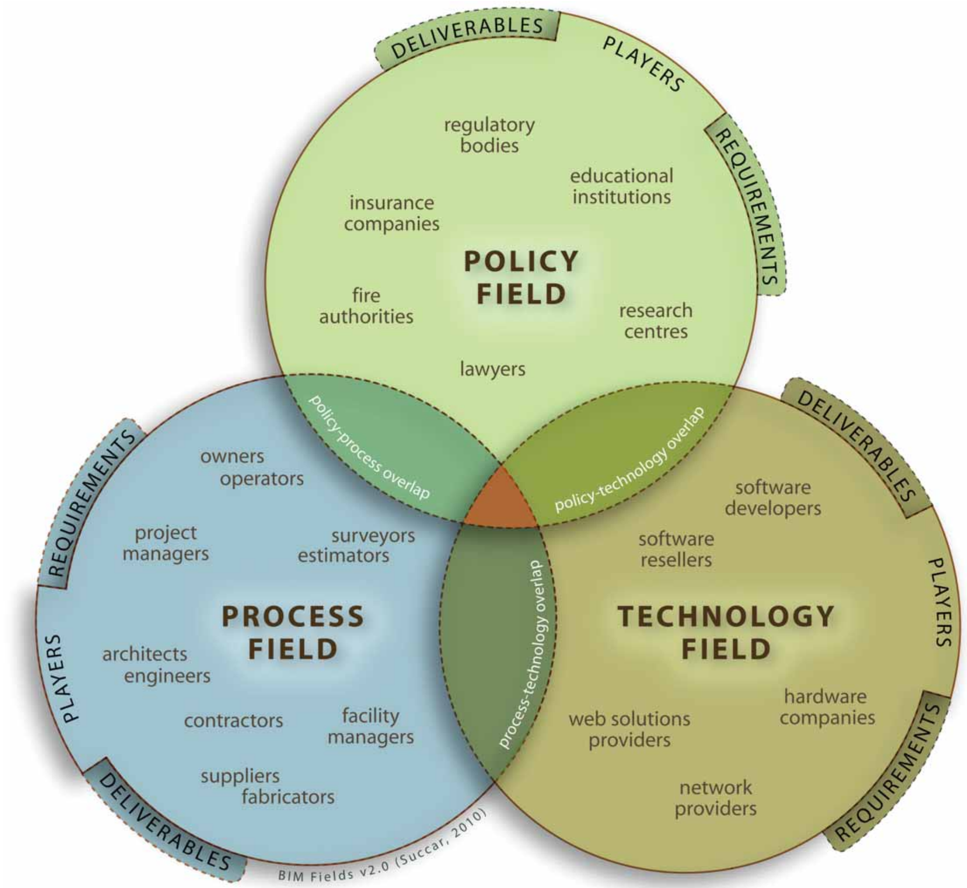


FIGURE 2 The interlocking fields of BIM activity

THE NEED FOR BIM PERFORMANCE METRICS

BIM use needs to be assessable if the productivity improvements that result from its implementation are to be made apparent. Without such metrics, teams and organizations are unable to consistently measure their own successes and/or failures. Performance metrics enable teams and organizations to assess their own competencies in using BIM and, potentially, to benchmark their progress against that of other practitioners. Furthermore, robust sets of BIM metrics lay the foundations for formal certification systems, which could be used by those procuring construction projects to pre-select BIM service providers.

DEVELOPING BIM METRICS AND BENCHMARKS

Although it is important to develop metrics and benchmarks for BIM performance assessment, it is equally important that these metrics are accurate and able to be adapted to different industry sectors and organizations. Considerable insight can be gained from the performance measurement tools developed for other industries but it would be foolhardy to rely on any tool which is not designed for the specific requirements of the task in question. Those required to measure key BIM deliverables/requirements across the construction supply chain are no exception.

This article describes a set of metrics purposefully developed to measure the specifics of BIM performance. To increase their reliability, adoptability and usability for different stakeholders, the first-named author identified the following performance criteria. The metrics should be:

- *Accurate*: Well-defined and able to measure performance at high levels of precision.
- *Applicable*: Able to be utilized by all stakeholders across all phases of a project's lifecycle.
- *Attainable*: Achievable if defined actions are undertaken.
- *Consistent*: Yield the same results when conducted by different assessors.
- *Cumulative*: Set as logical progressions; deliverables from one act as prerequisites for another.
- *Flexible*: Able to be performed across markets, Organizational Scales and their subdivisions.
- *Informative*: Provide 'feedback for improvement' and 'guidance for next steps' (Nightingale & Mize, 2002, p. 19).
- *Neutral*: Not prejudice proprietary, non-proprietary, closed, open, free or commercial solutions or schemata.
- *Specific*: Serve the specific requirements of the *construction industry.*
- *Universal*: Apply equally across markets and geographies.
- *Usable*: Intuitive and able to be easily employed to assess BIM performance.

This article describes the development of a set of BIM performance metrics based on these guiding principles. It introduces a set of complementary knowledge components that enable BIM performance assessment and facilitate its improvement.

RESEARCH DESIGN

The investigations described in this article are part of a larger PhD study which addresses the question of how to represent BIM knowledge structures and provide models that facilitate the implementation of BIM in academic and industrial settings. It is grounded in a set of paradigms, theories, concepts and experiences which combine to form the view of the BIM domain reported here.

CONCEPTUAL BACKGROUND

According to Maxwell (2005), the conceptual background underpinning a study such as this is typically based on several sources including previous research and existing theories, the researcher's own experiential knowledge and thought experiments. Various theories (including systems theory (Ackoff, 1971; Chun, Sohn, Arling, & Granados, 2008), systems thinking (Chun et al., 2008), diffusion of innovation theory (Fox & Hietanen, 2007; Mutai, 2009; Rogers, 1995), technology acceptance models (Davis, 1989; Venkatesh & Davis, 2000) and complexity theory (Froese, 2010; Homer-Dixon, 2001) assisted in analysing the BIM domain and enriched the study's conceptual background. Constraints identified in these theories led to the development of a new theoretical framework based on an inductive approach '[more suitable for researchers who are more concerned about] the correspondence of their findings to the real world than their coherence with existing theories or laws' (Meredith, Raturi, Amoako-Gyampah, & Kaplan, 1989, p. 307).

METHODOLOGY AND VALIDATION

The five components of BIM performance measurement are some of the deliverables of the BIM framework developed after assessing numerous publicly available international guidelines (Succar, 2009). The framework itself is composed of a number of high-level concepts that interact to generate a set of guides and tools necessary to (i) facilitate BIM implementations; (ii) conduct BIM performance assessments; and (iii) generate multi-tiered educational curricula.

The theoretical underpinnings of the BIM framework have been 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). Framework components were then represented visually through a series of 'knowledge models' to reduce topic complexity (Tergan, 2003) and facilitate knowledge transfer to others (Eppler & Burkhard, 2005).

Many of the BIM framework's components – fields, stages, lenses, steps, competencies and several visual knowledge models – have been subjected to a process of validation through a series of international focus groups employing a mixed-model approach (Tashakkori & Teddlie, 1998). The results from these focus groups and their impact on the development of the five components of BIM performance measurement will be published separately.

THE FIVE COMPONENTS OF BIM PERFORMANCE MEASUREMENT

The first named author identified five BIM framework components as those required to enable accurate and consistent BIM performance measurement (Succar, 2010b). These include BIM capability stages, BIM maturity levels, BIM competency sets, Organizational Scales and Granularity Levels.

The following sections provide brief introductions to each component. They are followed by a step-by-step workflow which allows BIM capability and maturity assessments to be conducted.

BIM CAPABILITY STAGES

BIM capability is defined here as the basic ability to perform a task or deliver a BIM service/product. BIM capability stages (or BIM stages) define the *minimum BIM requirements* – the major milestones that need to be reached by teams or organizations as they implement BIM technologies and concepts. Three BIM stages separate 'pre-BIM', a fixed starting point representing *industry status before* BIM implementation, from 'post-BIM', a variable end-point representing the continually evolving goal of employing *virtually integrated* design, construction and operation (*vi*DCO) tools and concepts. (The term *vi*DCO is used in preference to integrated project delivery (IPD) as representing the ultimate goal of implementing BIM (AIA, 2007) to prevent any confusion with the term's evolving contractual connotations within the United States.) The stages are:

- *BIM stage 1*: object-based modelling;
- *BIM stage 2*: model-based collaboration;
- *BIM stage 3*: network-based integration.

BIM stages are defined by their *minimum* requirements. For example, to be considered as having achieved BIM capability stage 1, an organization needs to have deployed an object-based modelling software tool similar to ArchiCAD, Revit, Tekla or Vico. Similarly, for BIM capability stage 2, an organization needs to be engaged in a multidisciplinary 'model-based' collaborative project. To be considered at BIM capability stage 3, an organization needs to be using a network-based solution which links to external databases and shares object-based models with at least two other disciplines – a solution similar to a model server or BIMSaaS solution (BIMserver, 2011; Onuma, 2011; Wilkinson, 2008).

Each of these three capability stages may be further subdivided into competency steps. What differentiates stages from steps is that stages are *transformational* or *radical* changes, while steps are *incremental* ones (Henderson & Clark, 1990; Taylor & Levitt, 2005). The collection of steps involved in working towards or within a BIM stage (i.e. across the continuum from pre-BIM to post-BIM) is driven by different *perquisites for*, *challenges within* and *deliverables of* each BIM stage. In addition to their type (the competency set they belong to – refer to Section BIM competency sets), the following BIM steps can be also identified according to their location on the continuum shown in Figure 3:

- *A steps*: from pre-BIM status leading to BIM stage 1;
- *B steps*: from BIM stage 1 leading towards BIM stage 2;
- *C steps* from BIM stage 2 leading towards BIM stage 3;
- *D steps* from BIM stage 3 leading towards post-BIM.

BIM MATURITY LEVELS

The term 'BIM maturity' refers to the quality, repeatability and degree of excellence within a BIM capability. Although 'capability' denotes a *minimum ability* (refer to Section BIM capability stages), 'maturity' denotes *the extent of that ability* in performing a task or delivering a BIM service/product. BIM maturity's benchmarks are performance improvement milestones (or levels) that teams and organizations aspire to or

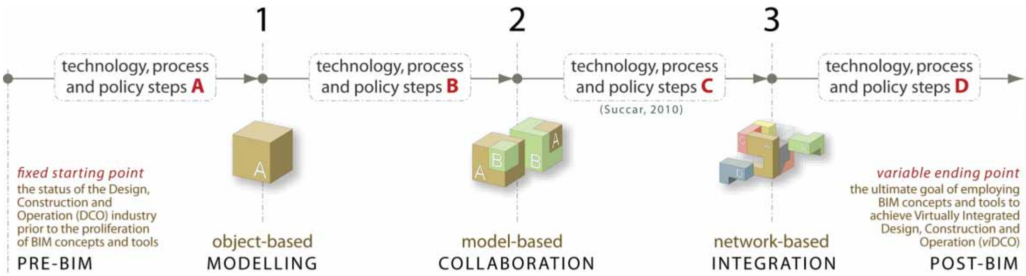


FIGURE 3 Step sets leading to or separating BIM stages – v1.1

work towards. In general, the progression from lower to higher levels of maturity indicates (i) improved control resulting from fewer variations between performance targets and actual results; (ii) enhanced predictability and forecasting of reaching cost, time and performance objectives; and (iii) greater effectiveness in reaching defined goals and setting new more ambitious ones (Lockamy III & McCormack, 2004) (McCormack, Ladeira, & Oliveira, 2008).

The concept of BIM maturity has been adopted from Software Engineering Institute's (SEI) capability maturity model (CMM) (SEI, 2008a), a process improvement framework initially intended as a tool to evaluate the ability of government contractors to deliver software projects. CMM originated in the field of quality management (Crosby, 1979) and was later developed for the benefit of the US Department of Defence (Hutchinson & Finnemore, 1999). Its successor, the more comprehensive capability maturity model integration (CMMI) (SEI, 2006a, 2006b, 2008c), continues to be developed and extended by the SEI, Carnegie Mellon University. Several CMM variants exist for other industries (Succar, 2010a) but they are all, in essence, specialized frameworks that assist stakeholders to improve their capabilities (Jaco, 2004) and benefit from process improvements. Example benefits include increased productivity and return on investment as well as reduced costs and post-delivery defects (Hutchinson & Finnemore, 1999).

Maturity models are typically composed of multiple maturity *levels*, or process improvement 'building blocks' or 'components' (Paulk, Weber, Garcia, Chrissis, & Bush, 1993). When the requirements of each level are satisfied, implementers can then build on established components to attempt 'higher' maturity. Although CMMs are not without their detractors (e.g. Bach, 1994; Jones, 1994; Weinberg, 1993), research conducted in other industries has already identified a correlation between improved process maturity and business performance (Lockamy III & McCormack, 2004).

The 'original' software industry CMM, however, is not applicable to the construction industry. It does not address supply chain issues, and its maturity levels do not account for the different phases of the lifecycle of a construction project (Sarshar et al., 2000). Although other efforts, derived from CMM, focus on the construction industry (refer to Table 1), there is no comprehensive maturity model/index that can be applied to BIM, its implementation stages, players, deliverables or its effect on project lifecycle phases.

The CMMs listed in Table 1 are similar in structure and objectives but differ in conceptual depth, industrial focus, terminology and target audience. A common theme is how CMMs employ simple experience-based classifications and benchmarks to facilitate continuous improvement within organizations. In analysing their suitability for developing a BIM-specific maturity index, most are broad in approach and can collectively form a basis for a range of BIM processes, technologies and policies. However, none easily accommodates the size of organizations being monitored. Also, from a terminology standpoint, there is insufficient differentiation between the notion of capability (an ability to perform a task) and that of maturity (the degrees of excellence in performing a task). This differentiation is critical when catering for staged BIM implementation as it responds to the disruptive and expansive nature of BIM.

To address the aforementioned shortcomings, the BIM maturity index (BIMMI) has been developed by

TABLE 1 Maturity models influencing the BIM maturity index

SAMPLE REPRESENTATION	ABBREVIATION, NAME – *ORGANIZATION* DESCRIPTION AND NUMBER OF MATURITY LEVELS

Category Number	A - Physical Accuracy of	B - IPD Methodology	C - Calculation Mentality	D - Location Awareness	E - Content Creation	F - Construction Data	G - As-Built Modeling	H - FM Data Richness
1	Basic Model Geometry	Creation of A BIM Execution Plan	Basic Model Information Export (Discipline)	Site Orientation	Geometrically Correct Content	Quantity Takeoffs	Post Bid Model Documentation	Space Management Data
2	Design Requirements	Introduction of Structural and MEP Model	IPD Integration	Existing Environment Awareness	Manufacturer's Specific	Object Scheduling	Coordination Modeling	Asset Management
3	Design Side Collision Detection	Model Managers Role Defined	Interdisciplinary Calculations	Global Accuracy	Design Intent	Material Procuremen t	Recapturing Design Intent	Manufacturer Specific Information
4	Model Accuracy Innovation	IPD Methodology Innovation	Calculations Innovation	Location Innovation	Content Innovation	Construction Innovation	As-Built Innovation	FM Data Innovation

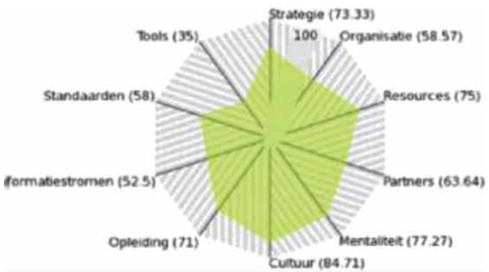
'Simplified matrix' – an Excel Worksheet from the BIM proficiency matrix (IU, 2009b)

BIM proficiency matrix – *The Indiana University Architect's Office*

The BIM proficiency matrix is 'used to assess the proficiency of a respondent's skill at working in a BIM environment'. The matrix is 'adaptable to project needs' and intends to communicate 'owner intent regarding BIM objectives' (IU, 2009a, pp. 15 and 16)

The BIM proficiency matrix is a static, multi-worksheet, MS Excel workbook (IU, 2009b) which includes eight categories to be assessed. Upon assessment, a score ranging from one to four points is assigned against each category. Points for each category are then tallied and the total BIM maturity score is calculated. The matrix identifies five 'BIM standards' which a project can achieve, should achieve or has already achieved depending on when the matrix is deployed

The five proficiency levels (or BIM standards) are: 'working towards BIM' – the lowest standard, 'certified BIM', 'silver', 'gold' and 'ideal' – the highest BIM maturity standard



Score representation (by category) from the sample BIM QuickScan report (TNO, 2010)

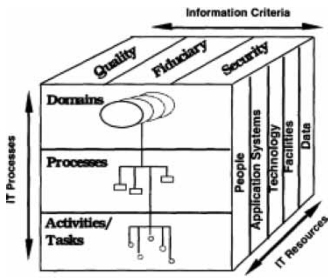
BIM QuickScan – *TNO Built Environment and Geosciences*

The BIM QuickScan tool aims to 'serve as a standard BIM benchmarking instrument in the Netherlands'.

The scan is intended to be performed 'in a limited time of maximum one day' (Sebastian & Van Berlo, 2010, pp. 255 and 258)

The BIM QuickScan Tool is organized around four chapters: organization and management, mentality and culture, information structure and information flow, and tools and applications. 'Each chapter contains a number of KPIs in the form of a multiple-choice questionnaire. . . With each KPI, there are a number of possible answers. For each answer, a score is assigned. Each KPI also carries a certain weighting factor. The sum of all the partial scores after considering the weighting factors represents the total score of BIM performance of an organization' (Sebastian & Van Berlo, 2010, pp. 258 and 259)

KPIs are assessed against a percentile score while 'Chapters', representing a collation of KPIs, are assessed against a five-level system (0 to 4).



(Lainhart, 2000)

COBIT, Control objects for information and related technology – *Information Systems Audit and Control Association (ISACA) and the IT Governance Institute (ITGI)*

The main objective of COBIT is to 'enable the development of clear policy and good practice for IT control throughout organizations' (Lainhart, 2000, p. 22)

The COBIT Maturity Model is 'an IT governance tool used to measure how well developed the management processes are with respect to internal controls. The maturity model allows an organization to grade itself from non-existent (0) to optimized (5)' (Pederiva, 2003, p. 1). COBIT includes six *maturity levels* (non-existent, initial/ad hoc, repeatable but intuitive, defined process, managed and measurable and optimized), four *domains* and 34 *control objectives*

Note: There is some alignment between ITIL (OGC, 2009) and COBIT with respect to IT governance within organizations (Sahibudin, Sharifi, & Ayat, 2008) of value to BIM implementation efforts

Level	Focus	Process Areas	Result
5 Optimizing	*Continuous process improvement*	Organizational Innovation & Deployment Causal Analysis and Resolution	Productivity & Quality
4 Quantitatively Managed	*Quantitative management*	Organizational Process Performance Quantitative Project Management	
3 Defined	*Process standardization*	Requirements Development Technical Solution Product Integration Verification Validation Organizational Process Focus Organizational Process Definition Organizational Training Integrated Project Management Risk Management Decision Analysis and Resolution	
2 Managed	*Basic project management*	Requirements Management Project Planning Project Monitoring & Control Supplier Agreement Management Measurement and Analysis Process & Product Quality Assurance Configuration Management	
1 Initial	*Competent people and heroics*		

Source: NASA, Software Engineering Process Group. http://bit.ly/CMMI-NASA

CMMI, Capability maturity model integration – *Software Engineering Institute/Carnegie Melon*

Capability maturity model® integration (CMMI) is a process improvement approach that helps integrate traditionally separate organizational functions, set process improvement goals and priorities, provide guidance for quality processes, and provide a point of reference for appraising current processes (SEI, 2006b, 2006c, 2008a, 2008b, 2008c)

CMMI has five *maturity levels* (for staged representation, six capability levels for continuous representation), 16 core *process areas* (22 for CMMI-DEV and 24 for CMMI-SVC) and one to four *goals* for each process area

The five maturity levels are: initial, managed, defined, quantitatively managed and optimizing

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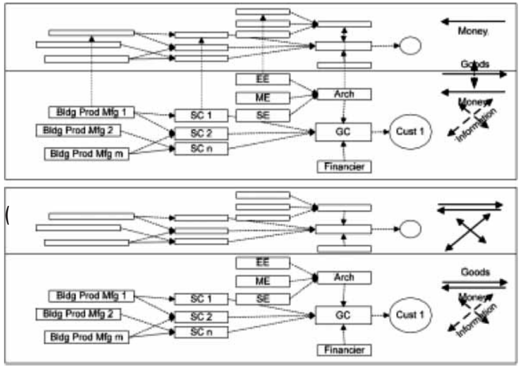
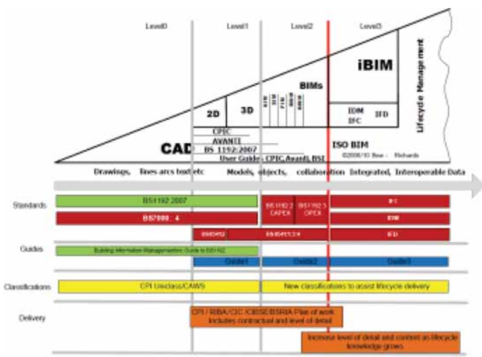
TABLE 1 Continued

SAMPLE REPRESENTATION	ABBREVIATION, NAME – *ORGANIZATION* DESCRIPTION AND NUMBER OF MATURITY LEVELS



(Vaidyanathan & Howell, 2007)

CSCMM, construction supply chain maturity model
'Construction supply chain management (CSCM) refers to the management of information, flow, and money in the development of a construction project' as mentioned in (Vaidyanathan & Howell, 2007, p. 170)
CSCMM has four maturity stages: ad hoc, defined, managed and controlled

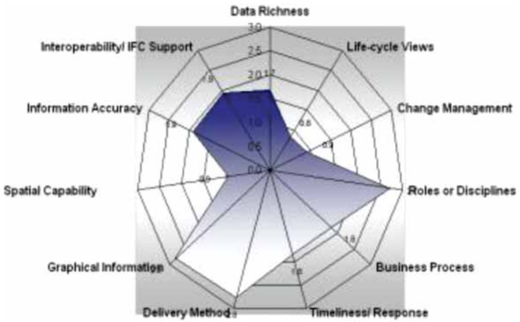


(BIS, 2011)

iBIM – integrated Building Information Modelling

The iBIM maturity model – introduced in Bew, Underwood, Wix, and Storer (2008) – has been devised 'to ensure clear articulation of the standards and guidance notes, their relationship to each other and how they can be applied to projects and contracts in industry' (BIS, 2011, p. 40)

The iBIM model identifies specific capability targets (not performance milestones) for the UK Construction Industry covering technology, standards, guides, classifications and delivery (total number of topics not defined). Targets for each topic are organized under one or more loosely defined maturity levels (0–3)

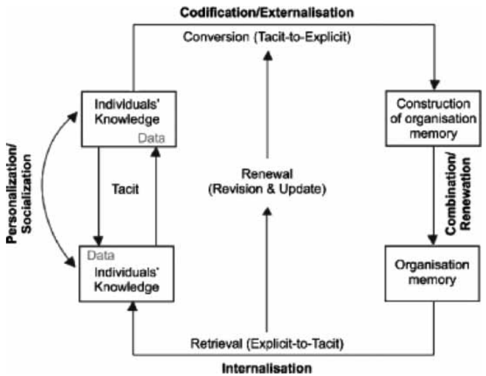


(Suermann, Issa, & McCuen, 2008)

I-CMM, Interactive capability maturity model – *National Institute for Building Sciences (NIBS) Facility Information Council (FIC)*

This I-CMM is closely coupled with the NBIMS effort (version1, part 1) and establishes 'a tool to determine the level of maturity of an individual BIM as measured against a set of weighted criteria agreed to be desirable in a Building Information Model' (Suermann, et al., 2008, p. 2; NIST, 2007; NIBS, 2007)

The ICMM has 11 'areas of interest' measured against 10 maturity levels



(Arif, Egbu, Alom, & Khalfan, 2009)

Knowledge retention maturity levels

Arif et al. (2009) introduced four levels of knowledge retention maturity

Knowledge management is an integral part of BIM capability and subsequent maturity. The matrix thus incorporates these levels: (i) knowledge is shared between employees, (ii) shared knowledge is documented (transferred from tacit to explicit), (iii) documented knowledge is stored and (iv) stored knowledge is accessible and easily retrievable (Arif, et al., 2009)

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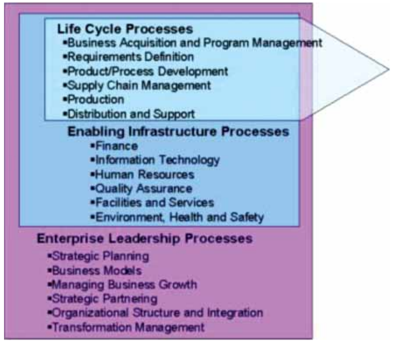
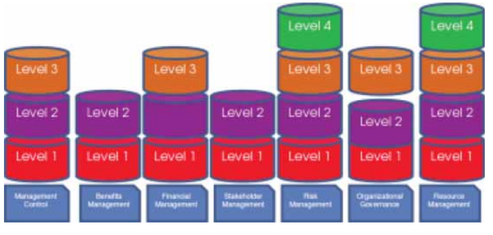
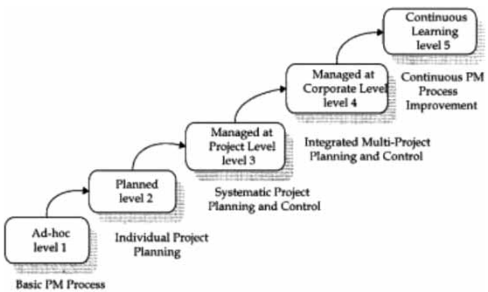
TABLE 1 Continued

SAMPLE REPRESENTATION	ABBREVIATION, NAME – *ORGANIZATION* DESCRIPTION AND NUMBER OF MATURITY LEVELS
 (Nightingale & Mize, 2002)	LESAT, Lean Enterprise Self-Assessment Tool – *Lean Aerospace Initiative (LAI) at the Massachusetts Institute of Technology (MIT)* LESAT is focused on 'assessing the degree of maturity of an enterprise in its use of 'lean' principles and practices to achieve the best value for the enterprise and its stakeholders' (Nightingale & Mize, 2002, p. 17). LESAT has 54 lean practices organized within three assessment sections: lean transformation/leadership, life cycle processes and enabling infrastructure *and* five maturity levels: some awareness/sporadic, general awareness/informal, systemic approach, ongoing refinement and exceptional/innovative
 (OGC, 2008)	P3M3, Portfolio, programme and project management maturity model – *Office of Government Commerce* The P3M3 provides 'a framework with which organizations can assess their current performance and put in place improvement plans with measurable outcomes based on industry best practice' (OGC, 2008, p. 8) The P3M3 has five maturity levels: awareness, repeatable, defined, managed and optimized

(SEI, 2008d)

P-CMM®, People capability maturity model v2 – *Software Engineering Institute/Carnegie Melon*
P-CMM is an 'organizational change model' and a 'roadmap for implementing workforce practices that continuously improve the capability of an organization's workforce' (SEI, 2008d, pp. 3 and 15)
P-CMM has five maturity levels: initial, managed, defined, predictable and optimizing



(Kwak & Ibbs, 2002)

$(PM)^2$, Project management process maturity model

The project management process maturity $(PM)^2$ model 'determines and positions an organization's relative project management level with other organizations'. It also aims to integrate PM 'practices, processes, and maturity models to improve PM effectiveness in the organization' (Kwak & Ibbs, 2002, p. 150)
$(PM)^2$ has five maturity levels: initial, planned, managed at project level, managed at corporate level and continuous learning

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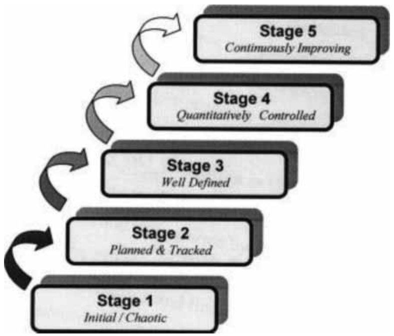
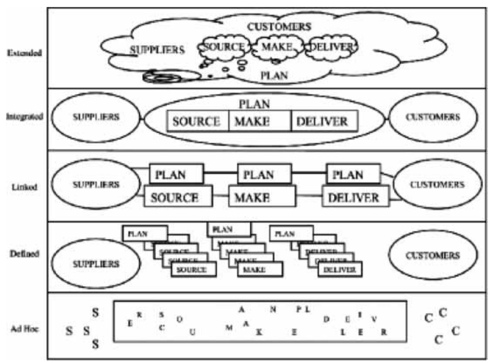
TABLE 1 Continued

SAMPLE REPRESENTATION	ABBREVIATION, NAME – *ORGANIZATION* DESCRIPTION AND NUMBER OF MATURITY LEVELS
 (Hutchinson & Finnemore, 1999)	SPICE, Standardized process improvement for construction enterprises – *Research Centre for the Built and Human Environment, The University of Salford* SPICE is a project which developed a framework for continuous process improvement for the construction industry. SPICE is an ‘evolutionary step-wise model utilizing experience from other sectors, such as manufacturing and IT’ (Hutchinson & Finnemore, 1999, p. 576; Sarshar et al., 2000) SPICE has five stages: initial/chaotic, planned & tracked, well defined, quantitatively controlled, and continuously improving
 (Lockamy III & McCormack, 2004)	Supply chain management process maturity model *and* business process orientation (BPO) Maturity Model The model conceptualizes the relation between process maturity and supply chain operations as based on the supply-chain operations reference model (Stephens, 2001). The model’s maturity describes the ‘progression of activities toward effective SCM and process maturity. Each level contains characteristics associated with process maturity such as predictability, capability, control, effectiveness and efficiency’ (Lockamy III & McCormack, 2004, p. 275; McCormack, 2001). The five maturity levels are: ad hoc, defined, linked, integrated and extended

Other maturity models – or variation on listed maturity models – include those on software process improvement (Hardgrave & Armstrong, 2005), IS/ICT management capability (Jaco, 2004), interoperability (Widergren, Levinson, Mater, & Drummond, 2010), project management (Crawford, 2006), competency (Gillies & Howard, 2003) and financial management (Doss, Chen, & Holland, 2008)

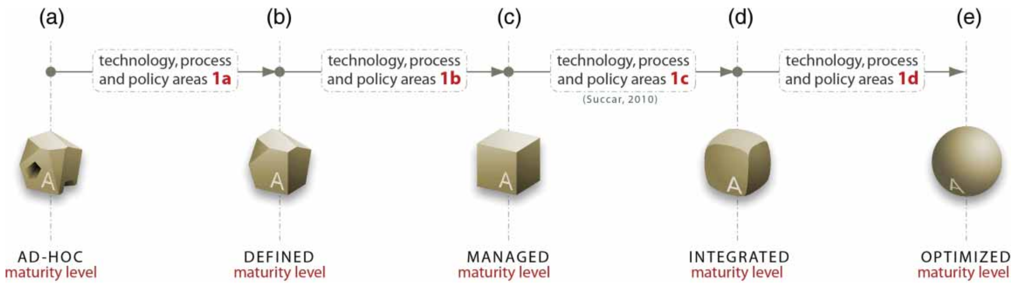


FIGURE 4 Building Information Modelling maturity levels at BIM stage 1

analysing and then integrating these and other maturity models used across different industries. The BIMMI has been customized to reflect the specifics of BIM capability, implementation requirements, performance targets and quality management. It has five distinct levels: (a) initial/ ad hoc, (b) defined, (c) managed, (d) integrated and (e) optimized (Figure 4). Level names were chosen to reflect the terminology used in many maturity models, to be easily understandable by DCO stakeholders and to reflect increasing BIM maturity from ad hoc to continuous improvement (Table 2).

BIM COMPETENCY SETS

A BIM competency set is a hierarchical collection of individual competencies identified for the purposes of implementing and assessing BIM. In this context, the term competency reflects a generic set of abilities suitable for implementing as well as assessing BIM capability and/or maturity. Figure 5 illustrates how the BIM framework generates BIM competency sets out of multiple fields, stages and lenses (Succar, 2009).

BIM competencies are a direct reflection of BIM requirements and deliverables and can be grouped into three sets, namely technology, process and policy:

Technology sets in *software, hardware* and *data/ networks*. For example, the availability of a BIM tool allows the migration from drafting-based to object-based workflow (a requirement of BIM stage 1)

Process sets in *resources, activities/workflows, products/services, and leadership/management*. For example, collaboration processes and database-sharing skills are necessary to allow model-based collaboration (BIM stage 2).

Policy sets in *benchmarks/controls, contracts/ agreements and guidance/supervision*. For example, alliance-based or risk-sharing contractual agreements are pre-requisites for network-based integration (BIM stage 3).

Figure 6 provides a partial mind-map of BIM competency sets shown at Granularity Level 2 (for an explanation of Granularity Levels, please refer to Section BIM granularity levels).

BIM ORGANIZATIONAL SCALES

To allow BIM performance assessments to respect the diversity of markets, disciplines and company sizes, an Organizational Scale (OScale) has been developed. The scale can be used to customize assessment efforts and is depicted in Table 3.

BIM GRANULARITY LEVELS

Competency sets include a large number of individual competencies grouped under numerous headings (shown in Figure 6). To enhance BIM capability and maturity assessments and to increase their flexibility, a granularity 'filter' with four Granularity Levels (GLevels) has been developed. Progression from lower to higher levels of granularity indicates an increase in (i) assessment breadth, (ii) scoring detail, (iv) formality and (iv) assessor specialization.

Using higher Granularity Levels (GLevel 3 or 4) exposes more detailed competency areas than lower Granularity Levels (GLevel 1 or 2). This variability enables the preparation of several BIM performance measurement tools ranging from low-detail, informal and self-administered assessments to high-detail, formal and specialist-led appraisals. Table 4 provides more information about the four Granularity Levels.

TABLE 2 A non-exhaustive list of terminology used by CMMs to denote maturity levels including those used by the BIM maturity index

MATURITY MODELS	MATURITY LEVELS					
	0	1 *or* a	2 *or* b	3 *or* c	4 *or* d	5 *or* e
BIM maturity index		Initial/ad hoc	Defined	Managed	Integrated	Optimized
COBIT, Control objects for information and related technology	Non-existent	Initial/ad hoc	Repeatable but intuitive	Defined process	Managed & measurable	Optimized
CMMI, Capability maturity model integration (staged representation)		Initial	Managed	Defined	Quantitatively managed	Optimizing
CMMI (continuous representation)	Incomplete	Performed	Managed	Defined	Quantitatively managed	Optimizing
CSCMM, Construction supply chain maturity model		Ad-hoc	Defined	Managed	Controlled	N/A
LESAT, Lean enterprise self-assessment tool		Awareness/ Sporadic	General awareness/ informal	Systemic approach	Ongoing refinement	Exceptional/ innovative
P-CMM®, People capability maturity model		Initial	Managed	Defined	Predictable	Optimizing
P3M3, Portfolio, programme and project management maturity model		Awareness	Repeatable	Defined	Managed	Optimized
$(PM)^2$, Project management process maturity model		Ad-hoc	Planned	Managed at project level	Managed at corporate level	Continuous learning
SPICE, Standardized process improvement for construction enterprises		Initial/chaotic	Planned & tracked	Well defined	Quantitatively controlled	Continuously improving
Supply chain management process maturity model		Ad hoc	Defined	Linked	Integrated	Extended

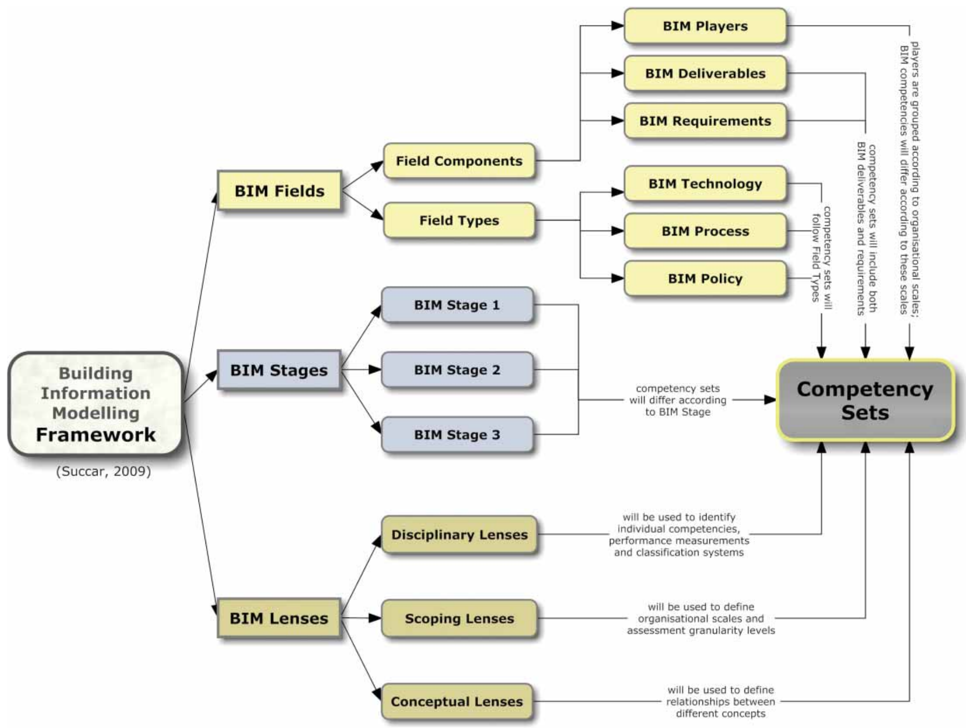


FIGURE 5 Structure of BIM competency sets v1.0

Granularity Levels increase or decrease the number of competency areas used for performance assessment. For example, the mind map provided in Figure 6 reveals *10 competency areas* at GLevel 1 and *41 competency areas* at GLevel 2. Also, at GLevels 3 and 4, the number of competency areas available for performance assessment increases dramatically as shown in Figure 7.

The partial mind-map shown in Figure 7 reveals many additional competency areas under GLevel 3, such as data types and data structures. At GLevel 4, the map reveals even more detailed competency areas including structured and unstructured data, which in turn branch into computable and non-computable components (Fallon & Palmer, 2007; Kong et al., 2005; Mathes, 2004).

APPLYING THE FIVE ASSESSMENT COMPONENTS

The aforementioned five complementary BIM framework components (capability stages, maturity levels, competency sets, Organizational Scales and Granularity Levels) allow performance assessments to be conducted involving combinations of these components. The guiding principles discussed in Section Developing BIM metrics and benchmarks all apply. To manage all possible configurations, a simple assessment and reporting workflow has been developed (Figure 8).

The workflow shown in Figure 8 identifies the five steps needed to conduct a BIM performance assessment. Starting with an extensive pool of generic BIM competencies – applicable across DCO disciplines and organizational sizes – assessors can first filter-out non-applicable competency sets, conduct a series of assessments based on the competencies remaining and then generate appropriate assessment reports.

A FINAL NOTE

The five BIM framework components, briefly discussed in this article, provide a range of

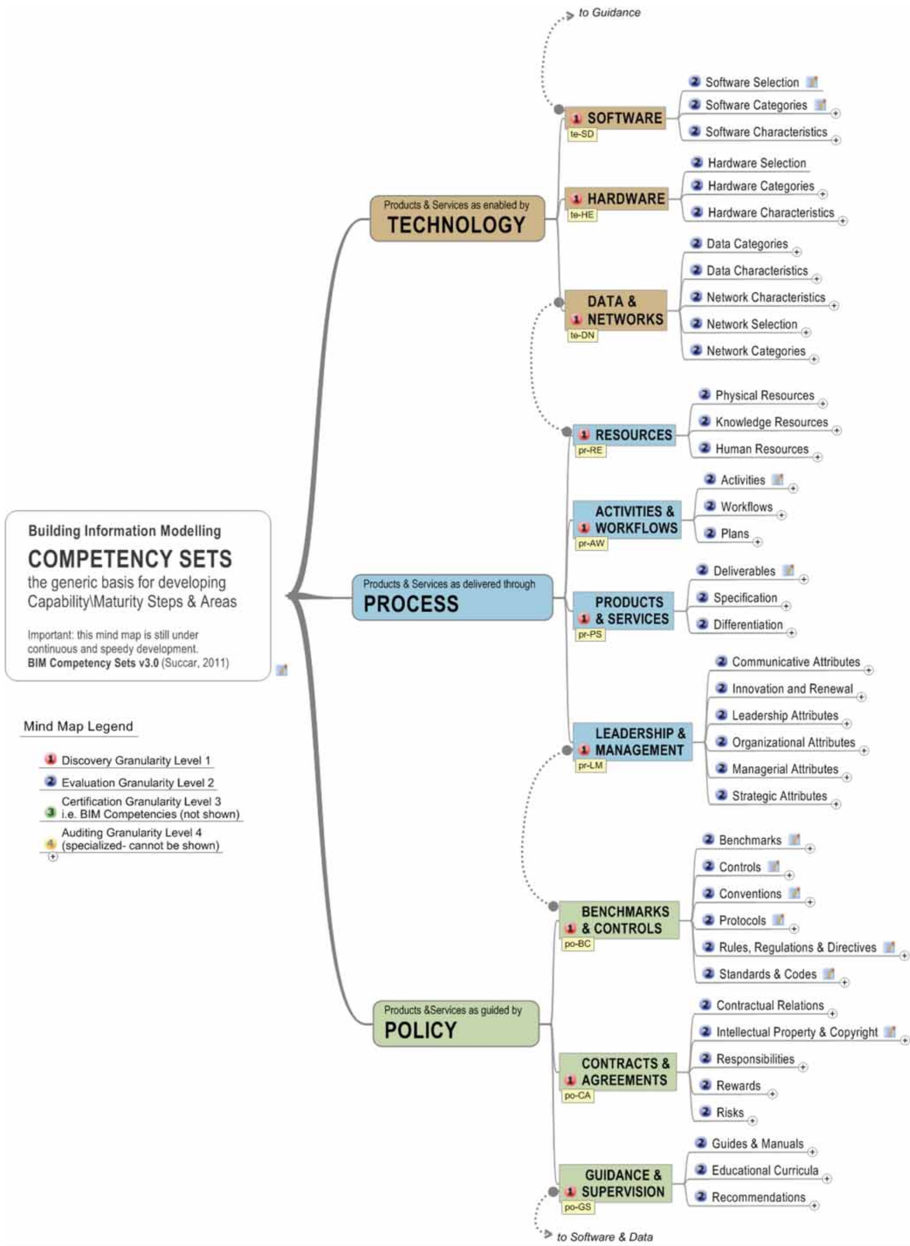


FIGURE 6 BIM Competency sets v3.0 – shown at Granularity Level 2

opportunities for DCO stakeholders to measure and improve their BIM performance. The components complement each other and enable highly targeted yet flexible performance analyses to be conducted. These range from informal self-assessments to highly detailed and formal organizational audits. Such a system of assessment can be used to standardize BIM implementation and assessment

TABLE 3 Organizational scales

LOW DETAIL			HIGH DETAIL			
NAME	SYM	GRANULARITY	NAME	SYM	GRANULARITY	SHORT DEFINITION
MACRO markets and industries	M	Markets 1	(Macro M)	M	Market 1	Markets are the 'world of commercial activity where goods and services are bought and sold'. http://bit.ly/pjB3c
			(Meso M)	Md	Defined market 2	Defined markets can be geographical, geopolitical or resultant from multi-party agreements similar to NAFTA or ASIAN
			(Micro M)	Ms	Sub-market 3	Sub-markets can be local or regional.
	I	Industries 4	(Macro I)	I	Industry 4	Industries are the *organized action of making of goods and services for sale*. Industries can traverse markets and may be service, product or project-based. The AEC industry is mostly Project-Based. http://bit.ly/ielY3
			(Meso I)	Is	Sector 5	A sector is a 'distinct subset of a market, society, industry, or economy whose components share similar characteristics' http://bit.ly/15UkZD
			(Micro I)	Id	Discipline 6	Disciplines are industry sectors, 'branches of knowledge, systems of rules of conduct or methods of practice'. http://bit.ly/7jT82
				Isp	Specialty 7	Specialty is a focus area of knowledge, expertise, production or service within a sub-discipline
MESO projects and their teams	P	Project teams 8	n/a	P	Project team 8	Project teams are temporary groupings of organizations with the aim of fulfilling predefined objectives of a project – a planned endeavour, usually with a specific goal and accomplished in several steps or stages. http://bit.ly/dqMYg
MICRO organizations units, their groups and members	O	Organizations 9	(Macro O)	O	Organization 9	An organization is a 'social arrangement which pursues collective goals, which controls its own performance, and which has a boundary separating it from its environment'. http://bit.ly/v7p9N
			(Meso O)	Ou	Organizational unit 10	Departments and units are specialized divisions of an organization. These can be co-located or distributed geographically
				Og	Organizational group (or team) 11	Organizational Groups consist of individual human resources assigned to perform an activity or deliver a set of assigned objectives. Groups (also referred to as organizational teams) can be physically co-located or formed across geographical or departmental lines
			(Micro O)	Om	Organizational member 12	Organizational members can be part of multiple organizational groups.

TABLE 4 BIM competency Granularity Levels v2.1

GLEVEL NUMBER, GLEVEL NAME, DESCRIPTION AND SCORING SYSTEM (NUMERICAL AND/OR NAMED)			OSCALE APPLICABILITY	ASSESSMENT BY, REPORT TYPE AND *GUIDE NAME*	
1	Discovery	A low detail assessment used for basic and semi-formal discovery of BIM capability and maturity. Discovery assessments yield a basic numerical score	All scales	Self	Discovery notes *BIMC&M discovery guide*
2	Evaluation	A more detailed assessment of BIM capability and maturity. Evaluation assessments yield a detailed numerical score	All scales	Self and peer	Evaluation sheets *BIMC&M evaluation guide*
3	Certification	A highly detailed appraisal of those competency areas applicable across disciplines, markets and sectors. Certification appraisal is used for structured (staged) capability and maturity and yields a formal, named maturity level	8 and 9	External consultant	Certificate *BIMC&M certification guide*
4	Auditing	Auditing is the most comprehensive appraisal type. In addition to competencies covered under certification, auditing appraises detailed competency areas including those specific to a market, discipline or a sector. Audits are highly customizable, suitable for non-structured (continuous) capability and maturity and yield a named maturity level plus a numerical maturity score for each competency area audited	8, 9, 10 and 11	Self, peer and external consultant	Audit report *BIMC&M auditing guide*

efforts, enable a structured approach to BIM education and training as well as establish a solid base for a formal BIM certification process.

After scrutiny of a significant part of the BIM framework through peer-reviewed publications and a series of international focus groups, the five

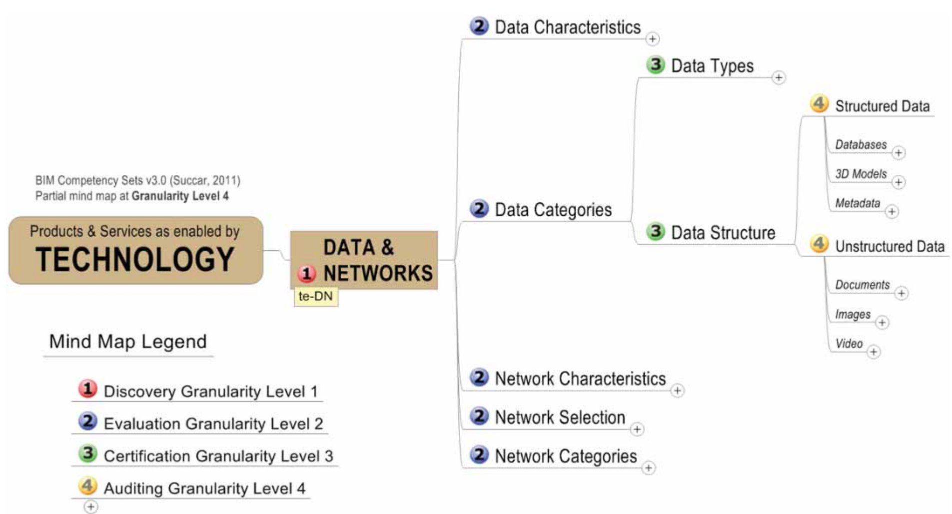


FIGURE 7 Technology competency areas at Granularity Level 4 – partial mind map v3.0

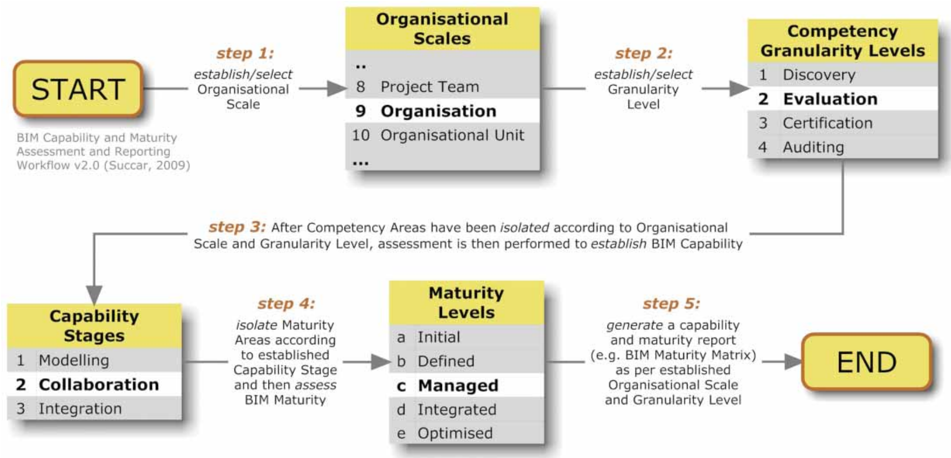


FIGURE 8 BIM capability and maturity assessment and reporting workflow diagram – v2.0

components and other related assessment metrics are currently being extended and field tested. Sample online tools (focusing on selected disciplines, at different granularities) are currently being formulated. All these form part of an ongoing effort to promote the establishment of an independent BIM certification body responsible for assessing and accrediting individuals, organizations and collaborative project teams. Subject to additional field testing and tool calibration, the five components may be well placed to consistently assess, and by extension improve, BIM performance.

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