Building Information Modelling Maturity Matrix

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ABSTRACT
Building Information Modelling (BIM) is an expanding collection of concepts and tools which have been attributed with transformative capabilities within the Architecture, Engineering, Construction and Operations (AECO) industry. BIM discussions have grown to accommodate increasing software capabilities, infinitely varied deliverables, and competing standards emanating from an abundance of overlapping definitions attempting to delineate the BIM term. This chapter will steer away from providing its own definition of BIM yet concurs with those identifying it as a catalyst for change (Bernstein, 2005) poised to reduce industry's fragmentation (CWIC, 2004), improve its efficiency (Hampson & Brandon, 2004) and lower its high costs of inadequate interoperability (NIST, 2004). In essence, BIM represents an array of possibilities and challenges which need to be understood and met respectively through a measurable and repeatable approach.
This chapter briefly explores the multi-dimensional nature of the BIM domain and then introduces a knowledge tool to assist individuals, organisations and project teams to assess their BIM capability, maturity and improve their performance (Figure 1).

The first section introduces BIM Fields and Stages which lay the foundations for measuring capability and maturity. Section 2 introduces BIM Competencies which can be used as active implementation steps or as performance assessment areas. Section 3 introduces an Organisational Hierarchy/Scale suitable for tailoring capability and maturity assessments according to markets, industries, disciplines and organisational sizes. Section 4 explores the concepts behind 'capability maturity models' and then adopts a five-level BIM-specific Maturity Index (BIMMI). Section 5 introduces the BIM Maturity Matrix (BIm³), a performance measurement and improvement tool which identifies the correlation between BIM Stages, Competency Sets, Maturity Levels and Organisational Scales. Finally, Section 6 introduces a Competency Granularity Filter which enables the tailoring of BIM tools, guides and reports according to four different levels of assessment granularity.

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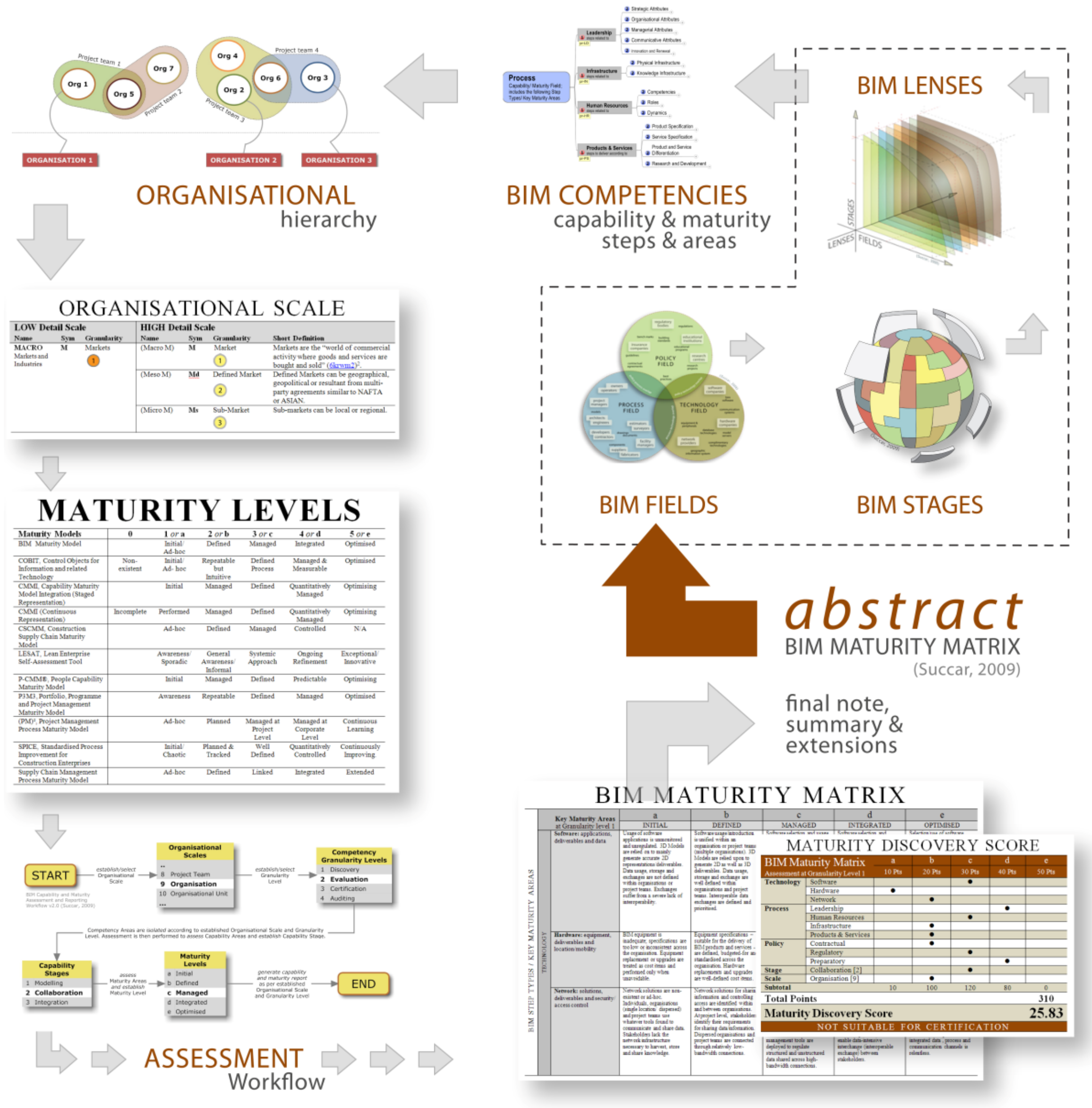


Figure 1. Visual Abstract

1 Building Information Modelling: a brief introduction

Building Information Modelling is a set of interacting policies, processes and technologies (Succar, 2009) generating a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Penttilä, 2006). This definition is one of tens of attempts to delimit the BIM domain which - as a term- continues to expand in coverage and connotation. It is important – if we acknowledge BIM's value in assisting the AECO industry and are inclined to assist in its systematic adoption - to identify the domain's knowledge structures, internal dynamics and implementation requirements. These can be best represented through a tri-axial understanding of the BIM domain (Figure 2):

- *BIM Fields* of activity identifying domain 'players', their 'requirements' and 'deliverables'.
- *BIM Stages* delineating minimum capability benchmarks.
- *BIM Lenses* providing the depth and breadth of enquiry necessary to identify, assess and qualify BIM Fields and BIM Stages.

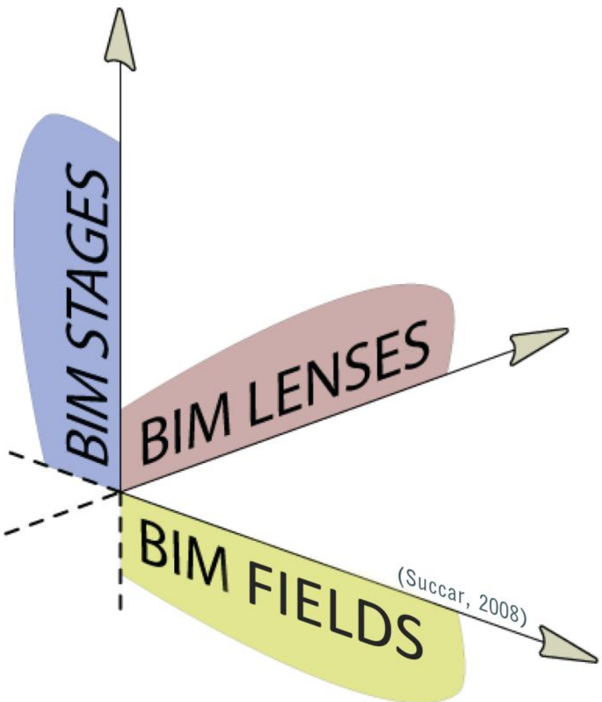


Figure 2. BIM framework: Fields, Stages and Lenses – tri-axial model

BIM Fields

The BIM domain is comprised of three interlocking yet distinctive *fields of activity* (Figure 3): Technology, Process and Policy. Each one of these BIM fields has its own players, requirements and deliverables. BIM players can be individuals, teams, organisations or other groupings as discussed later in Section 3.

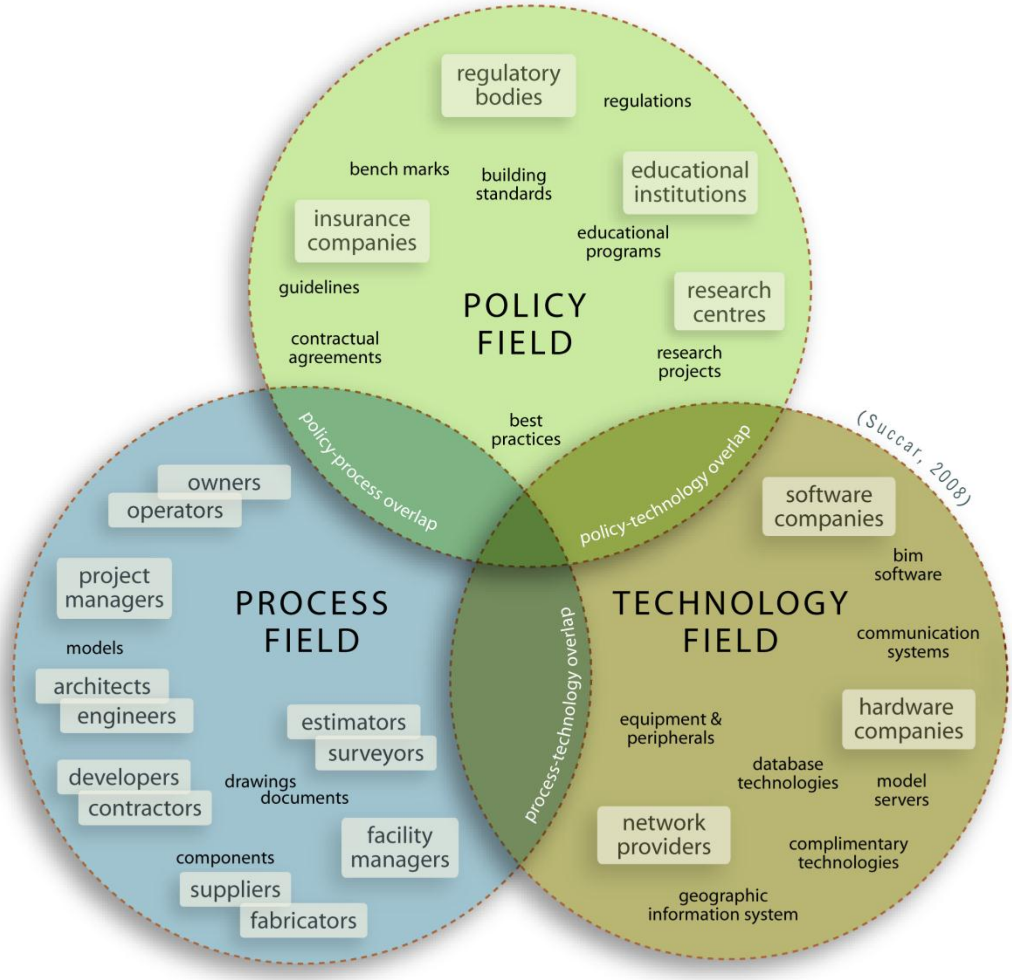
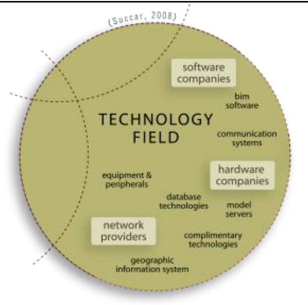
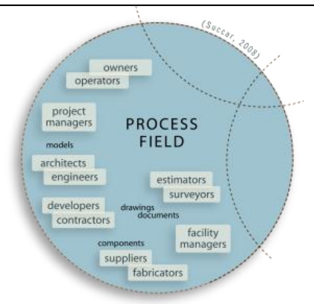
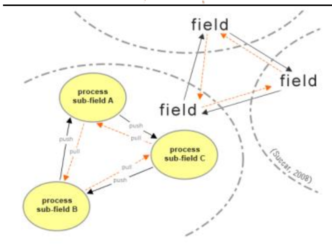
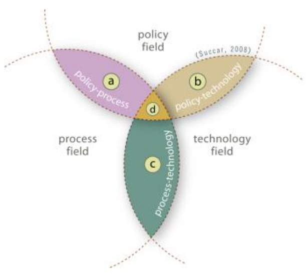


Figure 3. Three interlocking Fields of BIM activity– venn diagram

BIM Fields have been identified using 'conceptual clustering' of observable knowledge objects within the AECO industry. These clusters have been 'inductively inferred' through a strategy of observation and discovery (Michalski, 1987). The three BIM Fields interact within the AECO industry generating new products, services and roles. Table 1 summarises each of the three fields, their interactions and overlaps:

Table 1. BIM Fields, their interactions and overlaps

BIM FIELDS

	The **Technology Field** clusters a group of players who specialise in developing software, hardware, equipment and networking systems necessary to increase efficiency, productivity and profitability of AECO sectors. These include organisations which generate software solutions and equipment of direct and indirect applicability to the design, construction and operation of facilities.
	The **Process Field** clusters a group of players who procure, design, construct, manufacture, use, manage and maintain structures. These include facility owners, architects, engineers, contractors, facility managers and all other AECO industry players involved in the ownership, delivery and operations of buildings or structures.
	The **Policy Field** clusters a group of players focused on preparing practitioners, delivering research, distributing benefits, allocating risks and minimising conflicts within the AECO industry. These players do not generate any construction products but are specialised organisations - like insurance companies, research centres, educational institutions and regulatory bodies – which play a pivotal preparatory, regulatory and contractual roles in the design, construction and operations process.
	**BIM Interactions** are push-pull knowledge transactions occurring *within* or *between* fields. Push mechanisms (Holsapple & Joshi, 2006) transfer knowledge from one player or field to another while pull mechanisms transfer knowledge to satisfy a request by another player or field. Sample transactions include data transfers, team dynamics and contractual relationships between fields and their players.
	The three distinct fields overlap as they share players, requirements and deliverables. These **BIM Overlaps** between fields are exemplified in two cases below: *Case 1*: when a BIM deliverable requires input from two or more players or fields. For example, the development and implementation of non-proprietary interoperable schema (like Industry Foundation Classes) necessitates the joint effort of Policy players (researchers) as well as Technology players (software developers). *Case 2:* when players pertaining to one field generate deliverables classified in another. For example, the Australian Institute of Architects is an 'industry body' - whose members are Process players (architects) - generating Policy deliverables (guidelines and best practices).

BIM Stages

There are voluminous possibilities attributed to BIM representing an array of challenges which need to be addressed by Architecture, Engineering, Construction and Operations (AECO) stakeholders. Having identified the BIM Fields, this section identifies the multiple stages which delineate capability milestones.

BIM capability is the *basic ability* to perform a task, deliver a service or generate a product. BIM Capability Stages (or BIM Stages) define the major milestones to be achieved by teams and organisations as they adopt BIM technologies and concepts. BIM Stages identify a fixed starting point (the status before BIM implementation), three fixed BIM stages and a variable ending point which allows for unforseen future advancements in technology. This chapter uses the term Pre-BIM to represent industry status prior to BIM implementation and Integrated Project Delivery (IPD) to denote an *approach to* or an *ultimate goal of* implementing BIM (AIA, 2007). BIM Stages include technology, process and policy components and are as follows:

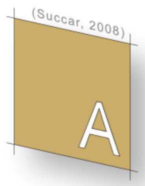
- *BIM Stage 1:* object-based modelling
- *BIM Stage 2:* model-based collaboration
- *BIM Stage 3:* network-based integration

BIM Stages are defined by their *minimum requirements*. As an example, for an organisation to be considered at BIM Capability Stage 1, it needs to have deployed an object-based modelling software tool. Similarly for BIM Capability Stage 2, an organisation needs to be part of a multidisciplinary model-based collaborative project. To be considered at BIM Capability Stage 3, an organisation must be using a network-based solution (like a model server) to share object-based models with at least two other disciplines. Table 2 expands on the above BIM Capability Stages starting with Pre-BIM and ending with a brief description of Integrated Project Delivery (IPD):

Table 2. Pre-BIM, BIM Capability Stages and Integrated Project Delivery

BIM CAPABILITY

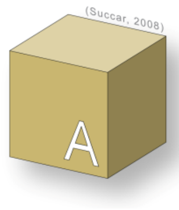
Pre-BIM status
Disjointed Project Delivery



The construction industry is characterised by adversarial relationships where contractual arrangements encourage risk avoidance and risk shedding. Much dependence is placed on 2D documentation to describe a 3D reality. Even when some 3D visualisations are generated, these are often disjointed and reliant on two-dimensional documentation and detailing. Quantities, cost estimates and specifications are generally neither derived from the visualisation model nor linked to documentation. Similarly, collaborative practices between stakeholders are not prioritised and workflow is linear and asynchronous. Under pre-BIM conditions, industry suffers from low investment in technology and lack of interoperability (CWIC, 2004) (NIST, 2004).

The graphical symbol (left) represents 2D hand-drawn, 2D computer-aided drafting or 3D non-object based software technologies similar to AutoCAD® and SketchUP®.

BIM Stage 1
Object-based Modelling

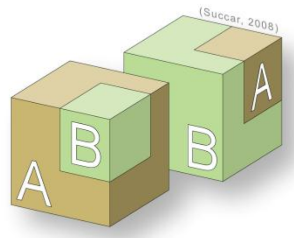


The graphical symbol above represents a single-disciplinary 3D model exemplified by an architect's ArchiCAD®, a structural engineer's Revit® or a steel detailer's Tekla® model.

BIM implementation is initiated through the deployment of an 'object-based 3D parametric software tool' similar to ArchiCAD®, Revit®, Digital Project® and Tekla®. At Stage 1, users generate single-disciplinary models within either design [D], construction [C] or operations [O] – the three Project Lifecycle Phases. Modelling deliverables include architectural design models [D] and duct fabrication models [C] used primarily to automate generation and coordination of 2D documentation and 3D visualisation. Other deliverables include basic data exports (e.g. door schedules, concrete volumes, FFE costs,...) and light-weight 3D models (e.g. 3D DWF, 3D PDF, NWD, etc...) which have no modifiable parametric attributes.

Collaborative practices at Stage 1 are similar to pre-BIM status and there are no significant model-based interchanges between different disciplines. Data exchanges between project stakeholders are uni-directional and communications continue to be asynchronous and disjointed. As only minor process changes occur at Stage 1, pre-BIM contractual relations, risk allocations and organisational behaviour persist. However, the semantic nature of object-based models and their 'hunger' for early and detailed resolution of design and construction challenges encourage 'fast-tracking' of Project Lifecycle Phases - when a project is still executed in a phased manner yet design and construction activities are overlapped to save time (Jaafari, 1997).

BIM Stage 2
Model-based Collaboration



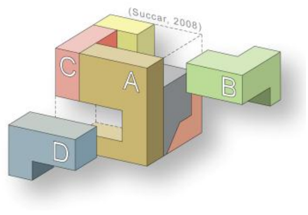
The graphical symbol (above) represents the interchange of 3D models between two different disciplines (A and B). This can be exemplified by two-way linking of Revit® Architectural and Structural models (a proprietary interoperable exchange) or the interchange of IFC- files exported out of multi-disciplinary BIM applications (a non-proprietary interoperable exchange).

Having developed single-disciplinary modelling expertise during Stage 1 implementations, Stage 2 players actively collaborate with other disciplinary players. Collaboration may occur in several technical ways following each player's selection of BIM software tools. Two different examples of model-based collaboration include the interchange (interoperable exchange) of models or part-models through 'proprietary' formats (e.g. between Revit® Architecture and Revit® Structure through the .RVT file format) and non-proprietary formats (e.g. between ArchiCAD® and Tekla® using the IFC file format).

Model-based collaboration can occur within one or between two Project Lifecycle Phases. Examples of this include the Design-Design interchange of architectural and structural models [DD], the Design-Construction interchange of structural and steel models [DC] and the Design-Operations interchange of architectural and facility maintenance models [DO]. It is important to note that only one 'collaborative model' needs to hold 3D geometric data to allow for semantic BIM interchanges between two disciplines. An example of this is the [DC] interchange between a 3D object-based model (e.g. Digital Project®), scheduling database (e.g. Primavera® or MS project®) or a cost estimating database (e.g. Rawlinsons or Timberline®). Such interchanges allow the generation of 4D (time analysis) and 5D (cost estimating) studies respectively.

Although communications between BIM players continue to be asynchronous, pre-BIM demarcation lines separating roles, disciplines and lifecycle phases start to fade. Some contractual amendments become necessary as model-based interchanges augment and start replacing document-based workflows. Stage 2 also alters the granularity of modelling performed at each lifecycle phase as higher-detail construction models move forward and replace (partially or fully) lower-detail design models.

BIM Stage 3
Network-based Integration



At this capability stage, semantically-rich integrated models are created, shared and maintained collaboratively across Project Lifecycle Phases. This integration can be achieved through 'model server' technologies (using proprietary, open or non-proprietary formats), single-integrated/distributed-federated databases (Bentley, 2003) (Liaserin, 2003), Cloud Computing or SaaS (Software as a Service)(Wilkinson, 2008). BIM Stage 3 models become interdisciplinary nD models (Lee et al., 2003) allowing complex analyses at early stages of virtual design and construction. At this Stage, model deliverables extend beyond semantic object properties to include business intelligence, lean construction principles, green policies and whole lifecycle costing. Collaborative work now 'spirals iteratively' around an extensive, unified and sharable data model (Edgar, 2007). From a process perspective, synchronous interchange of model and document-based data cause project lifecycle phases to overlap extensively forming a phase-less process.

The graphical symbol (above) represents the integration of 3D models using a network-based technology. Each of the single-disciplinary models (represented by capital letters) is an integral part of the resulting inter-disciplinary model.

Integrated Project Delivery
Interdependent, real-time models

Integrated Project Delivery, a term popularised by the American Institute of Architects California Council (AIA, 2007) is, in the author's view, suitable for representing a long-term vision of BIM as an amalgamation of domain technologies, processes and policies. The term is generic enough and potentially more readily understandable by industry than "Fully Integrated and Automated Technology" (FIATECH, 2005), Integrated Design Solutions (İLAL, 2007) or "nD Modelling" (Lee et al., 2003) as three prominent examples. The selection of Integrated Project Delivery (IPD) as the 'goal' of BIM implementations is not to the exclusion of other visions appearing under different names. On the contrary, the path from Pre-BIM (a fixed starting point), passing through three well defined Stages towards a loosely defined IPD is an attempt to include all pertinent BIM visions irrespective of their originating sources.

The graphical symbol (above) represents the delivery and continuous evolution of a highly integrated multi-dimensional model connected to multiple external databases and knowledge sources in real-time. These include services' grid, building management systems, geographic information systems (GIS), cost databases, operations business logic, etc...

BIM Lenses

BIM Lenses are distinctive layers of analysis (Figure 4) applied to Fields and Stages to generate *knowledge views* which 'abstract' the BIM domain and control its complexity by removing unnecessary detail (Kao & Archer, 1997). Lenses allow domain researchers to selectively focus on any aspect of the AECO industry and generate knowledge views that either (a) highlight observables which meet the research criteria or (b) filter out those that do not. In this chapter, a 'scoping' lens/filter (Succar, 2009) will be transparently applied to identify Organisational Scales (Section 3) and assessment Granularity Levels (Section 5).

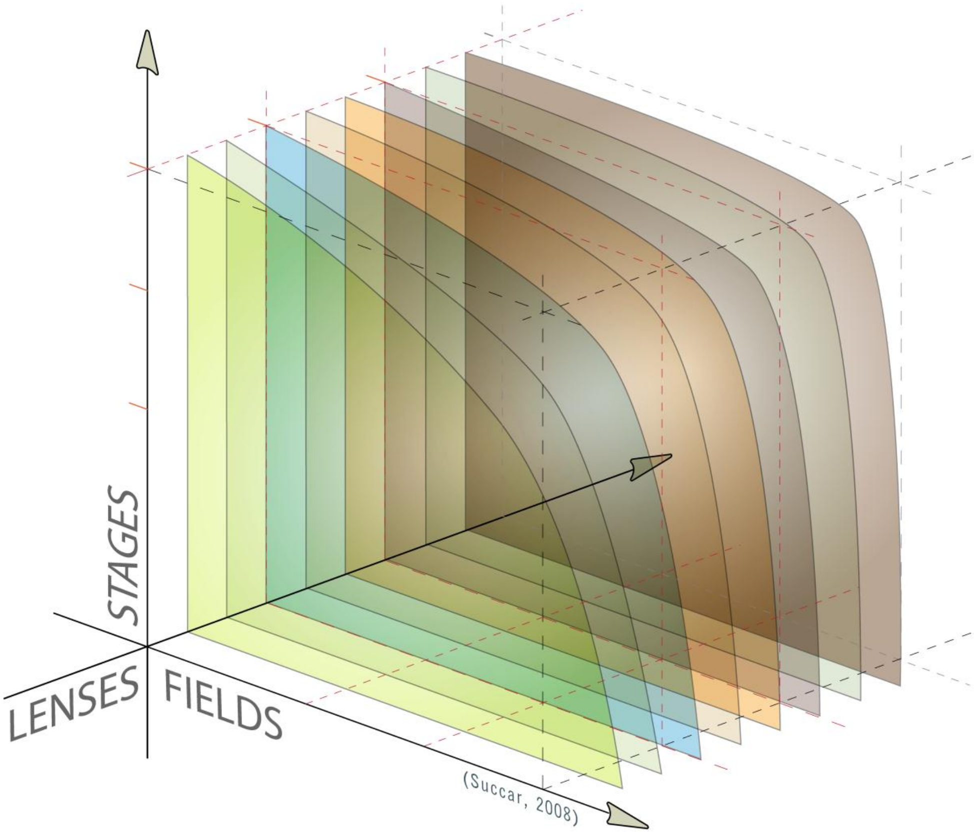


Figure 4. BIM Lenses – tri-axial model

2 BIM Competency Sets

A BIM Competency represents a BIM Player's ability to satisfy a BIM Requirement or generate a BIM Deliverable. A BIM Competency Set is a hierarchical collection of individual competencies identified for the purposes of BIM implementation and assessment. BIM Competency Sets follow the same classification as BIM Fields and are explored in Figure 5. A short description is also provided below:

- *Technology Sets* in *software, hardware* and *networks*. For example, the availability of a BIM tool allows the migration from drafting-based to object-based workflow (BIM Stage 1)
- *Process Sets* in *Leadership, Infrastructure, Human Resources* and *Products/Services*. For example, collaboration processes and database-sharing skills are necessary to allow model-based collaboration (BIM Stage 2).
- *Policy Sets* in *contracts, regulations* and *research/education*. For example, alliance-based and risk-sharing contractual agreements are pre-requisites to network-based integration (BIM Stage 3).

BIM Competencies are employed to establish BIM *Capability* or BIM *Maturity*[ii] benchmarks. They can also be used by teams and organisations to either *implement* BIM or *assess* its implementation. If BIM Competencies are used for the purposes of active implementation[iii], then they are referred to as BIM Steps. However, if they are used for assessing existing implementations, then they are referred to as BIM Areas. Not all BIM Competencies are of the same significance and can thus be separated into Key and non-Key Competencies.

[ii] The term *capability* in this chapter refers to the 'basic ability to perform a task' while the term *maturity* refers to the 'degrees of excellence in performing that task'(refer to Section 4).
[iii] This chapter uses an expanded definition of the term 'implementation'. Throughout this chapter, BIM implementation *does not only reflect the act of deploying* software, schema and their related processes but *represents all actions necessary to achieve, maintain and increase* BIM Capability and Maturity.

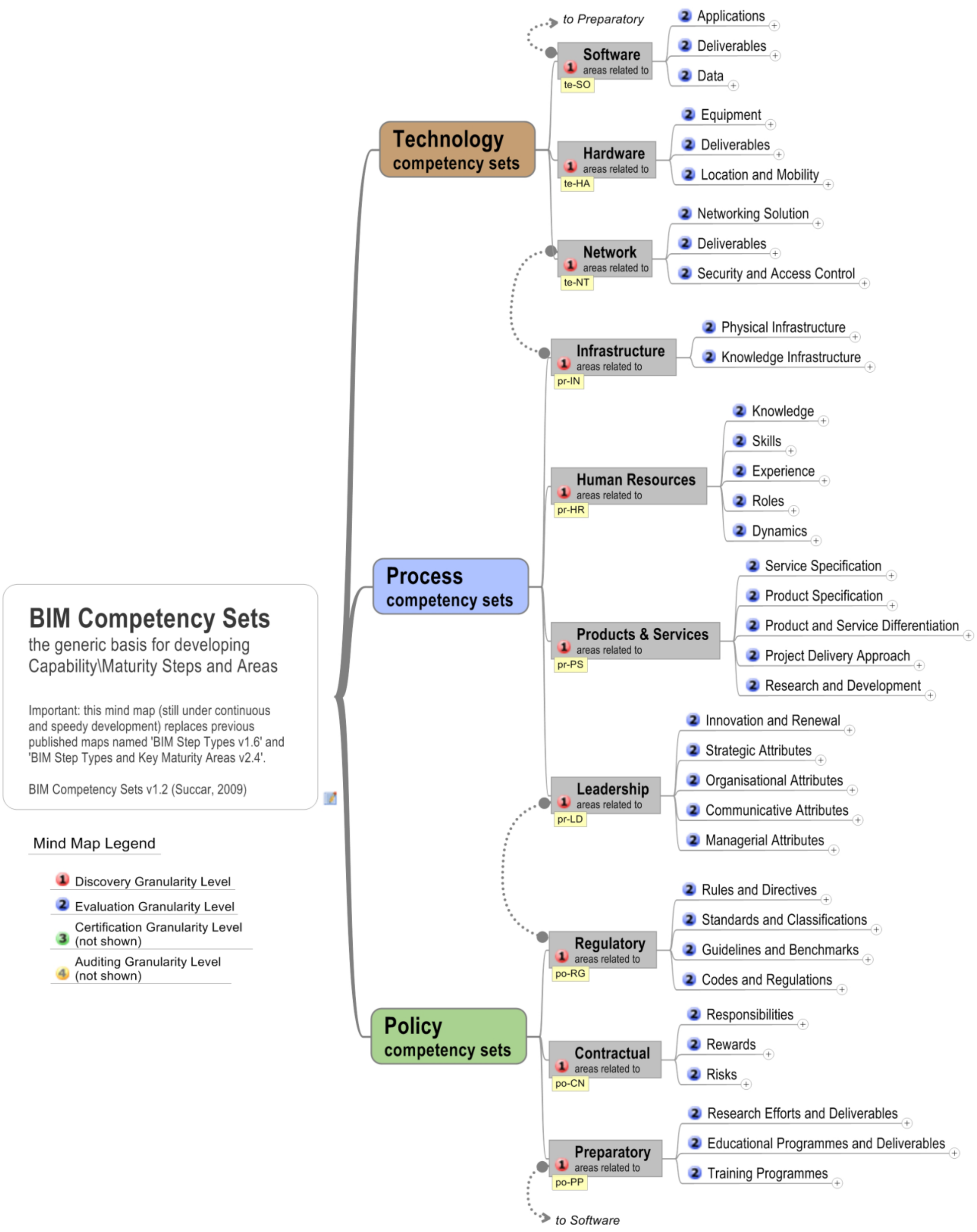


Figure 5. Indicative list of BIM Competency Sets v1.2 – mind map at Granularity Level 2

BIM Steps

The volume and complexity of changes required to achieve each of the three BIM Stages (refer to Table 2) are *transformational* and even *radical* (Henderson & Clark, 1990) (Taylor & Levitt, 2005). However, the passage from Pre-BIM to BIM Stage 1, through each of the three Stages and towards Integrated Project Delivery is populated by *incremental* or *evolutionary* steps. Identifying these BIM Steps is instrumental in enabling organisations and individuals to increase their BIM capability and maturity in a systematic way. Each BIM Stage has its own requirements and deliverables giving rise to numerous BIM Steps. These are collated into 'sets' according to their location on the implementation continuum (Figure 6):

- *A Steps:* from pre-BIM 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 Integrated Project Delivery

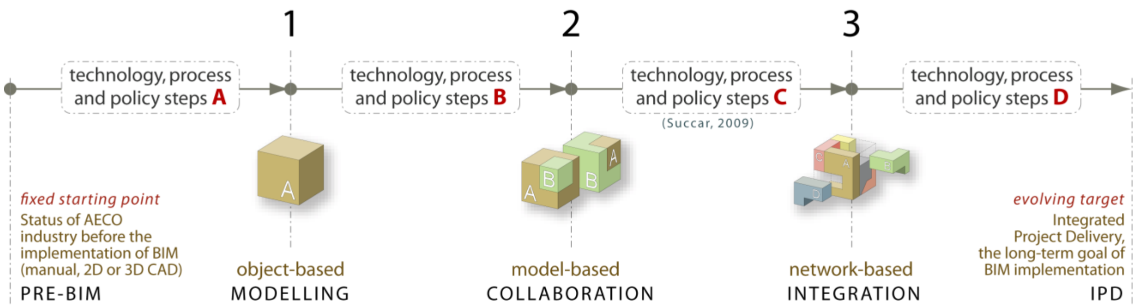


Figure 6. Step Sets leading to or separating BIM Stages – linear model v1.0

3 BIM Organisational Hierarchy

In the construction industry, every building, road or bridge construction project is a *unique* prototype involving a *similar* set of process stages (Wegelius-Lehtonen, 2001). This uniqueness, on one hand, is driven by multiple factors including the transient nature of project teams and the distinctive locational and environmental criteria of each project site. The similarity, on the other hand, is driven by long-held views of how construction projects should be conducted, reasonably stable organisational structures, slow-changing educational concepts and risk-averse insurance policies. This challenging duality of 'uniqueness' and 'similarity' is addressed by the BIM Framework through the development of an Organisational Hierarchy (Figure 7) and a granular Organisational Scale (Table 3). Both the Hierarchy and the Scale are based on the notions of *flexibility* - to cater for 'uniqueness' - and *uniformity* to cater for 'similarity':

- *Flexibility (of application):* BIM Capability and Maturity assessments can apply irrespective of organisational size, project type or how a project team is configured.

- *Uniformity (of measurement):* BIM Capability and Maturity assessments can be based on a set of standardised organisational subdivisions. Assessment results pertaining to an organisational unit, an organisation or a project team can be uniformly and respectively compared to another same-scale unit, organisation or project team.

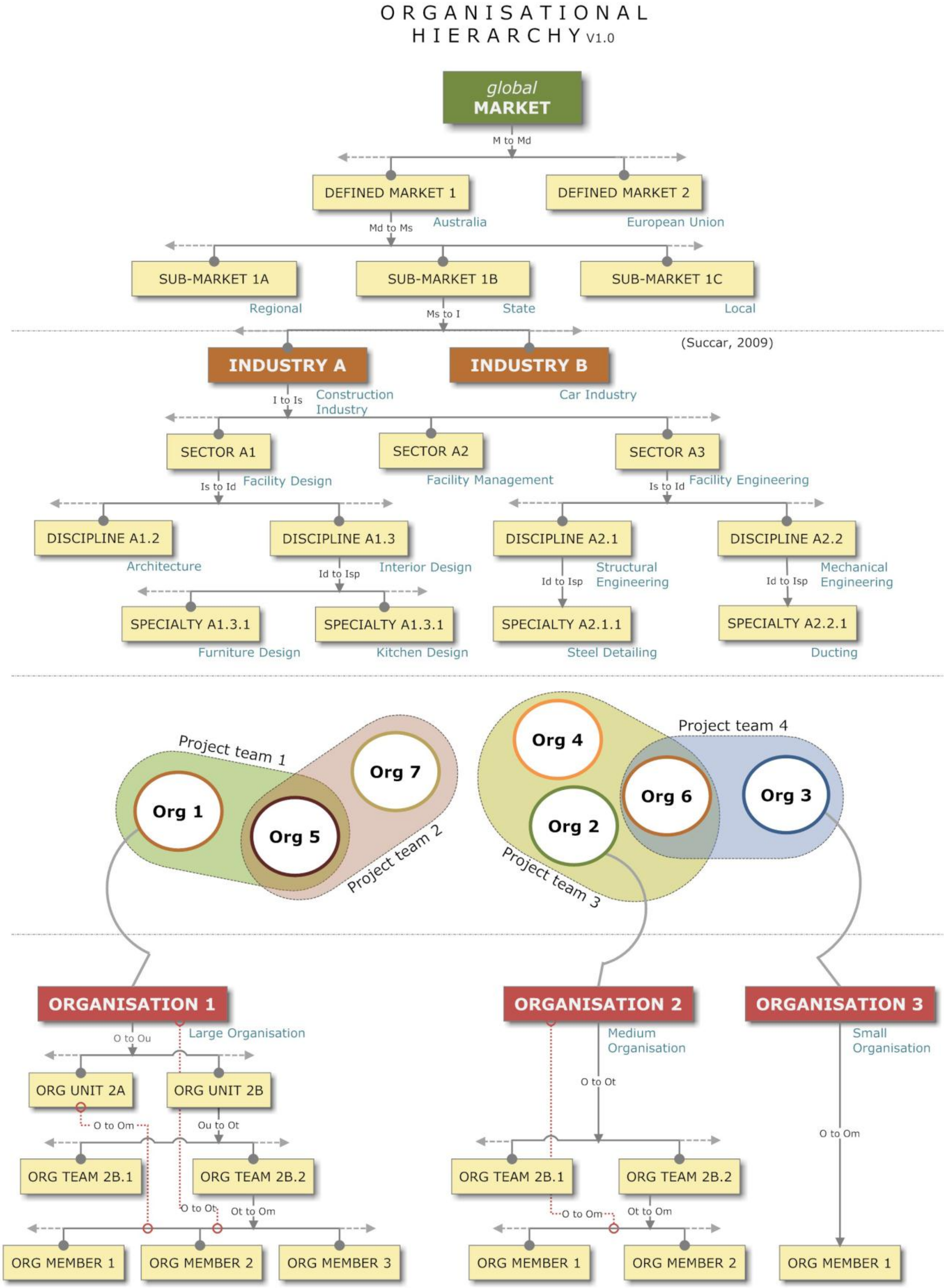


Figure 7. Organisational Hierarchy used for BIM Maturity – Tree view v1.0

Table 3 elaborates on the Organisational Hierarchy and introduces a granular scale. Acting as a BIM 'scoping filter' (Succar, 2009) the Organisational Scale (OScale) can be applied to BIM Players enabling a more-targeted approach to BIM implementation and assessment:

Table 3. Granular Organisational Scale

ORGANISATIONAL SCALE

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 organisations 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 Organisations, Units, their teams & members	**O**	Organisations 9	(Macro O)	**O**	Organisation 9	An organisation 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**	Organisational Unit 10	Departments and Units are specialised divisions of an organisation. These can be co-located or distributed geographically.
				Ot	Organisational Team 11	Organisational Teams consist of a group of individuals (human resources) assigned to perform an activity or deliver a set of assigned objectives. Teams can be physically co-located or formed across geographical or departmental lines.
			(Micro O)	**Om**	Organisational Member 12	Organisational members can be part of multiple Organisational Teams.

4 BIM Maturity Index

The BIM Maturity Index[iv] (BIMMI) includes a set number of Maturity Levels which signify the evolutionary improvement of processes, technologies and policies within each BIM Stage. A maturity level is a "well-defined evolutionary plateau that institutionalizes new capabilities for developing the organization's workforce" (SEI, 2008g).
Maturity levels allow for a basic distinction between *immature* and *mature* entities in terms of "systematic approach[es] to business processes" (Sarshar et al., 2000). With the exception of articles jestingly advocating multiple immaturity levels (Anthony, 1992), 'capability immaturity' or lack of maturity is typically identified as a fixed starting point. A collation of process maturity levels from 'immature' to 'highly mature' is typically referred to as a 'Maturity Model'.

Capability Maturity Models
The Capability Maturity Model (CMM) is a process improvement framework originally intended as a tool to evaluate the ability of government contractors to perform a software project. It was developed in the late 80s for the benefit of the US Department of Defence (Hutchinson & Finnemore, 1999). It's successor, the more comprehensive Capability Maturity Model Integration (CMMI), continues to be developed and extended by the Software Engineering Institute, Carnegie Mellon University. Below is a short historical synopsis of CMM, the basis for numerous maturity models across many industries:

> *"The U.S. Department of Defense (DoD) is the world's largest software customer, spending over $30 billion per year on software during the 1980s. At that time, software projects constantly seemed to be in crisis mode and were frequently responsible for large delays and overruns in defense systems. To address this software crisis on a national scale, the DoD funded the development of the Software Engineering Institute (SEI), a federally-funded research and development center (FFRDC), at Carnegie Mellon University in Pittsburgh, PA. Humphrey brought his process maturity concepts to the SEI in 1986, where he founded its Software Process Program. Shortly after arriving, he received a request from the U.S. Air Force to develop a method for assessing the capability of its software contractors"(SEI, 2008f).*

[iv] The author prefers to use the term BIM Maturity Index instead of BIM Maturity Model to minimise semantic confusion every time the word 'model' is invoked.

Capability Maturity Models originated in the field of quality management (Crosby, 1979) and are frameworks identifying a set of standardised process improvement levels which allow implementers to achieve significant business benefits. These include increased productivity and Return On Investment (ROI) as well as reduced costs and post-delivery defects (Hutchinson & Finnemore, 1999). Maturity models are typically made of multiple maturity levels; each level provides a layer in the foundation for continuous process improvement. Levels comprise of a set of process goals that, when satisfied, stabilise an important component in the 'construction' process. Achieving each level of the maturity framework establishes a different component" (Paulk, Weber, Garcia, Chrissis, & Bush, 1993).

Although CMM is not without its detractors (Weinberg, 1993) (Jones, 1994) (Bach, 1994), research conducted within other industries have already identified the correlation between improving process maturity and business performance (Lockamy III & McCormack, 2004). Researchers have argued that

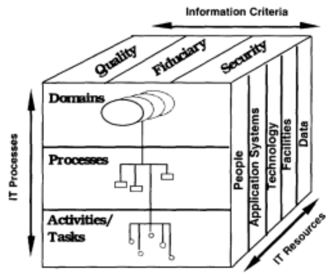
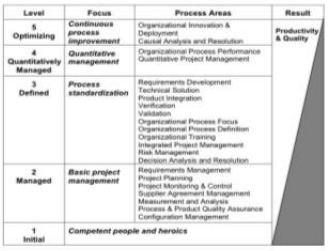
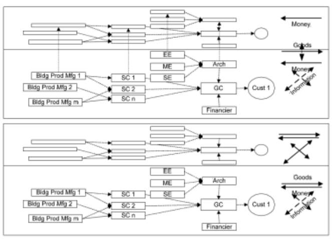
> *"to obtain consistently better results, it is (...) necessary to improve the process. For an organization to improve its capability, it is helpful to have a clear picture of the ultimate goal and a means to gauge progress along the way - hence the levels of the maturity model" (Jaco, 2004).*

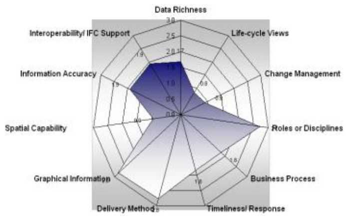
Currently available Capability Maturity Models are either specific to the software industry or focus mainly on the procedural aspects of an implementation process. The 'original' CMM is not applicable to the construction industry as it does not address supply chain issues and its maturity levels do not account for the different phases of a project lifecycle (Sarshar et al., 2000). Although there are a few (extensive) efforts which focus on the construction industry (refer to Table 5), 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.

Influences Shaping the BIM Maturity Index

It is important to benefit from existing maturity models/indices including those not intended specifically for the AECO industry. Many lessons can be learned and much experience can be gained by analysing, testing and then adopting some of the widely-used maturity terms, performance targets and quality assurance measures. Below are some of the published efforts that influenced the development of the BIM Maturity Index. Table 4 is a non-exhaustive list of source maturity models from different industries while Table 5 lists some of the widely adopted performance, excellence and quality management frameworks which influenced the BIM Maturity Matrix:

Table4. Maturity Models influencing the BIM Maturity Index

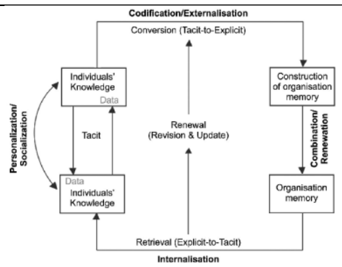
Sample Representation	**Abbreviation, Name** – *Organisation* Description and Number of maturity levels
 Image from (Lainhart IV, 2000)	**COBIT, Control Objects for Information and related Technology** – *Information Systems Audit and Control Association (ISACA) and the IT Governance Institute (ITGI)* The main objective of COBIT is to “enable the development of clear policy and good practice for IT control throughout organizations” (Lainhart IV, 2000). 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 nonexistent (0) to optimized (5)” (Pederiva, 2003). COBIT includes 6 *Maturity Levels* (Non-existent, Initial/ad hoc, Repeatable but Intuitive, Defined Process, Managed and Measurable and Optimised), 4 *Domains* and 34 *Control Objectives*. Note: There is some alignment between ITIL (OGC, 2009) and COBIT with respect to IT governance within organisations (Sahibudin, Sharifi, & Ayat, 2008) of value to BIM implementation efforts.
 Image 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, 2006a) (SEI, 2006b) (SEI, 2008a) (SEI, 2008b) (SEI, 2008c). CMMI has 5 *Maturity Levels* (for Staged Representation, 6 Capability Levels for Continuous Representation), 16 core *Process Areas* (22 for CMMI-DEV and 24 for CMMI-SVC), 1 to 4 *Goals* for each Process Area, each goal is comprised of *Practices*... The 5 Maturity Levels are: Initial, Managed, Defined, Quantitatively Managed and Optimising.
 (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). CSCMM has 4 Maturity Stages: Ad-hoc, Defined, Managed and Controlled.



(Suermann, Issa, & McCuen, 2008)

I-CMM, **Interactive Capability Maturity Model** - *National Institute for Building Sciences (NIBS) Facility Information Council (FIC)*

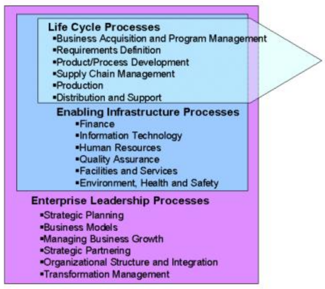
This I-CMM is closely coupled with the NBIMS effort (Version1, Part 1) and establishes “a tool to determine the level of maturity of an individual BIM as measured against a set of weighted criteria agreed to be desirable in a Building Information Model” (Suermann et al., 2008) (NIST, 2007) (NIBS, 2007). A more detailed discussion of this maturity model is offered in Section 4. The ICMM has 11 ‘Areas of Interest’ measured against 10 Maturity Levels.



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

Knowledge Retention Maturity Levels

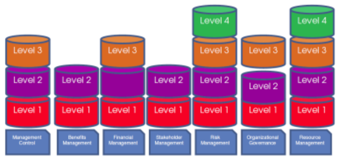
Arif, Egbu, Alom and Khalfan (2009) introduced 4 levels of knowledge retention maturity.
Knowledge management is an integral part of BIM capability and subsequent maturity. The Matrix thus incorporates these levels: (1) knowledge is shared between employees, (2) shared knowledge is documented (transferred from tacit to explicit), (3) documented knowledge is stored and (4) stored knowledge is accessible and easily retrievable (Arif et al., 2009).



(Nightingale & Mize, 2002)

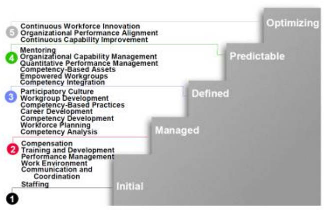
LESAT, **Lean Enterprise Self-Assessment Tool** - *Lean Aerospace Initiative (LAI) at the Massachusetts Institute of Technology (MIT)*

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).
LESAT has 54 Lean Practices organised within three Assessment Sections: Lean Transformation/ Leadership, Life Cycle Processes and Enabling Infrastructure *and* 5 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*

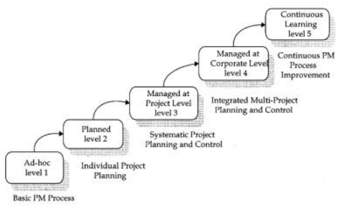
The P3M3 provides “a framework with which organizations can assess their current performance and put in place improvement plans with measurable outcomes based on industry best practice” (OGC, 2008).
The P3M3 has 5 Maturity Levels: Awareness, Repeatable, Defined, Managed and Optimised.



(SEI, 2008g)

P-CMM®, **People Capability Maturity Model** v2 – *Software Engineering Institute / Carnegie Melon*

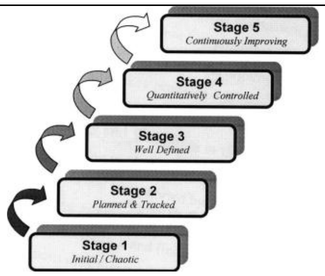
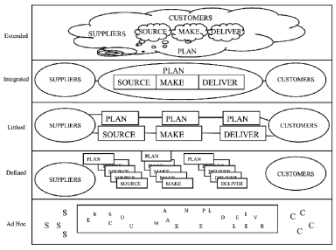
P-CMM is an “organizational change model” and a “roadmap for implementing workforce practices that continuously improve the capability of an organization’s workforce” (SEI, 2008g).
P-CMM has 5 Maturity Levels: Initial, Managed, Defined, Predictable and Optimising.



(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).
(PM)² has 5 Maturity Levels: Initial, Planned, Managed at Project Level, Managed at Corporate Level and Continuous Learning.

 (Hutchinson & Finnemore, 1999)	**SPICE, Standardised 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), (Sarshar et al., 2000). SPICE has 5 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[v] (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) (K. McCormack, 2001). The 5 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), **Project Management** (Crawford, 2006), **Competency** (Gillies & Howard, 2003) and **Financial Management** (Doss, Chen, & Holland, 2008).	

The above listed Capability Maturity Models are similar in structure and objectives but differ in conceptual depth, industrial focus, terminology and target audience. A common theme is how Capability Maturity Models employ few simple experience–based classifications and benchmarks to facilitate continuous improvement within organisations.

In analysing their suitability for the development of a BIM-specific maturity index, most were broad in approach and can collectively form a basis for a range of BIM processes, technologies and policies. However, none of the models surveyed were easily scalable across the twelve organisational scales (identified in Table 3). Also, from a terminology standpoint, there are not enough differentiation between the notion of *capability* (the ability to perform a task) and that of *maturity*[vi] (degrees of excellence in performing a task). This differentiation, in the author's view, is critical to cater for staged BIM implementation mandated by its disruptive and expansive nature.

It is also important to *not only* (i) identify BIM-specific maturity benchmarks, but to (ii) identify the detailed procedures to achieve these benchmarks and to (iii) develop a suitable scoring system for measuring teams and organisations against them. To attain all these objectives, the BIM Maturity Matrix – a performance improvement tool introduced in Section 5 – tries to learn from numerous Business Performance, Excellence and Quality Management models (Table 5):

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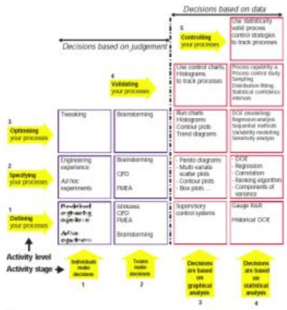
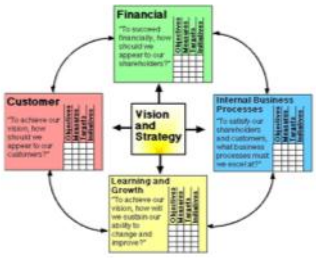
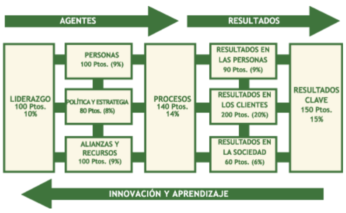
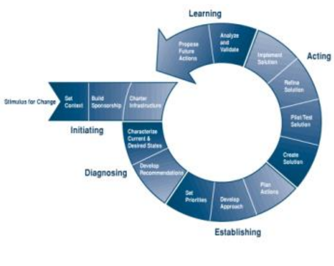
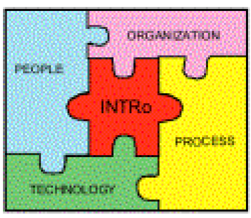
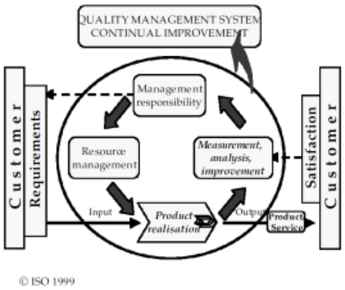
[v] For an overview of the latest Supply-chain Operations Reference Model (SCOR), version 9, please refer to http://bit.ly/SCORv9.

[vi] Please note that the terms Capability and Maturity are used differently by the Software Engineering Institute – Carnegie Melon, to denote CMMI "Continued Representation" and "Staged Representation" respectively.

Table 5. Performance, Excellence and Quality Management frameworks influencing the BIM Maturity Matrix

Sample Representation	**Abbreviation, Name** – *Organisation* Description and *specific influence on the BIM Maturity Matrix*
 Image from (NIST, 2008)	**Baldrige National Quality Program**, 2008 Criteria for Performance Excellence - *US Department of Commerce and National Institute of Standards and Technology (NIST)* The Malcolm Baldrige Quality Award is an overall performance award conducted by evaluating/scoring organisations against 7 Categories of Performance (using a 1000 points scale): Leadership, Strategic Planning, Customer/Market Focus, Information & Analysis, Human Resource Focus, Process Management, and Business Results (NIST, 2008). *Note: BIM Capability and Maturity assessment tools partially introduced in this chapter are influenced by Baldrige's "quality of documented processes" as well as its scoring system.*
 Link: http://bit.ly/Scorecard	**BSC**, **The Balanced Scorecard** The Balanced Scorecard is a performance management tool (Kaplan & Norton, 1996a) and a strategic management system (Kaplan & Norton, 1996b). BSC has 4 Perspectives: Learning and Growth, Business Process, Customer and Financial Perspectives. Using the Balanced Scorecard within the industry has been discussed in the Conceptual Framework for Performance Management in Construction (Kagioglou, Cooper, & Aouad, 2001). *Note: BIm³ and other BIM performance measurement tools benefited from BSC's approach in clarifying how organisations align overall BIM strategy with other organisational objectives.*
 Link: http://bit.ly/EFQMem	**EFQM Excellence Model** - *European Foundation for Quality Management* The EFQM (EFQM, 2008) Excellence Model is an annual award which includes 9 Concepts: Leadership, Policy & Strategy, People, Partnerships & Resources, Processes, Customer Results, People Results, Society Results and Key Performance Areas. Organisations may be assessed against, at least, 3 organisational maturity levels. *Note: BIM performance measurement tools can specifically benefit from EFQM and its applicability within the construction industry (Watson & Seng, 2001)*
 Link: http://bit.ly/IDEAL	**IDEAL**, **Initiating, Diagnosing, Establishing, Acting & Learning Model** – *Software Engineering Institute / Carnegie Melon* "The IDEAL model is an organizational improvement model that serves as a roadmap for initiating, planning, and implementing improvement actions". It has 5 Phases: Initiating, Diagnosing, Establishing, Acting and Learning (SEI, 2008d). *Note: The BIm³ - which includes BIM Stages and Steps as two of its components – is indirectly influenced by the IDEAL model.*
 Link: http://bit.ly/INTRO-SEI	**INTRo**, **IDEAL-based Based New Technology Rollout** - *Software Engineering Institute / Carnegie Melon* INTRo embodies "detailed how-to information needed to manage the introduction of a new technology, organized into a work breakdown structure of stages, steps, and tasks. Tips, checklists, guidelines, and tutorials accompany process descriptions". It has 7 Stages of new technology implementation: Project Initiation, Organizational Analysis, Technology-Based Solution Definition, Technology Selection and Testing, Whole Product Design, Breakthrough and Rollout (Levine, 2000) (SEI, 2008e). *Note: BIM Capability and Maturity assessments, introduced partially in this chapter, benefited from INTRo's subdivisions. This is more apparent in low-granularity BIM Competency Areas.*

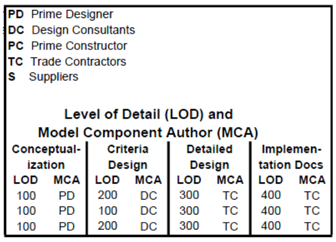


© ISO 1999, (Russell, 2000)

ISO 9000 Quality Management System - *The International Organization for Standardization*

The basic model of ISO 9000 includes 8 Principles (ISO, 2008a) (ISO, 2008b) which align somewhat with EFQM (Russell, 2000). ISO 9001 includes 20 clauses meant for services organisations (Jalote, 2000) and can be mapped and compared against the CMM (Paulk, 1994).

Note: BIm³ did not directly borrow from ISO standards but attempted to avoid any irresolvable clashes with its principles and terminology.



PD Prime Designer
DC Design Consultants
PC Prime Constructor
TC Trade Contractors
S Suppliers

Level of Detail (LOD) and Model Component Author (MCA)

Conceptual-ization		Criteria Design		Detailed Design		Implemen-tation Docs	
LOD	MCA	LOD	MCA	LOD	MCA	LOD	MCA
100	PD	200	DC	300	TC	400	TC
100	PD	100	DC	300	TC	400	TC
100	PD	200	DC	300	TC	400	TC

(AIA, 2008)

MPS, **Model Progression Specification** for Building Information, Integrated Project Delivery Models - *American Institute of Architects*

The MPS (AIA, 2008) is beneficial in establishing the optimum amount of details needed within a building information model at each project lifecycle phase and sub-phase. From a process improvement perspective, an organisation or a project team - implementing BIM with a degree of performance maturity - will need to establish its optimum Level of Detail to minimise *under* and/or *over* representation. The MPS has 5 Levels of Detail (LOD) measured against 4 Model Component Authors (MCA).

Note: BIm³ and other BIM Capability/Maturity tools incorporate LODs and MCAs as part of their assessments.

Other models of relevance and of potential benefit to BIm³ and other BIM Capability/Maturity assessment tools include: **ISO/IEC 15504**, **Information Technology - Process Assessment** Part 4: Guidance on use for process improvement and process capability determination - *International Standards Organisation* (ISO, 2004) and **ITIL**, **Information Technology Infrastructure Library** - *Office of Government Commerce (OGC) in UK* (OGC, 2009) (Cartlidge et al., 2007).

The above frameworks form a good basis to generate a comprehensive scoring system for measuring BIM Capability and Maturity. They will also guide the preparation of multiple knowledge tools tailored to assist industry stakeholders in *implementing* and *assessing* BIM in a systematic and repeatable fashion.

Focus on NBIMS Capability Maturity Model

Before introducing a new maturity index, it is important to properly evaluate existing BIM-specific maturity models. At the time this chapter was readied for publication, two efforts where publically available: the NBIMS' I-CMM and Indiana University's BIM Proficiency Matrix[vii]. Since not enough documentation - relating to Indiana University's effort - were located, this Section will exclusively focus on NBIMS' approach to BIM maturity assessment and reporting:

The U.S. National Building Information Model Standard™ "establishes standard definitions for building information exchanges to support critical business contexts using standard semantics and ontologies…[to be]…implemented in software". NBIM Standard Version 1 – Part 1 proposes a Capability Maturity Model (CMM) for "users to evaluate their business practices along a continuum or spectrum of desired technical level functionality" and "for use in measuring the degree to which a building information model implements a mature BIM Standard" (NIST, 2007).

There are two versions of NBIMS' CMM. The first is a static tabular version identifying eleven 'Areas of Interest' measured against ten Levels of increasing maturity (Figure 8). The second is the Interactive Capability Maturity Model (I-CMM), a multi-tab Microsoft Excel® workbook based on the static tabular model (NIBS, 2007). The I-CMM is intended for use as an 'internal tool' (internal to organisations) deployed to "determine the level of maturity of an individual BIM [project] as measured against a set of weighted criteria agreed to be desirable in a Building Information Model" (NIST, 2007) (Suermann et al., 2008). I-CMM focuses primarily on measuring BIM information management and "should not be used as a benchmark for any other metrics" including those related to architectural, engineering, construction and management. It is also not intended as a "tool to compare BIMs or BIM implementations" (NIST, 2007).

[vii] Indiana University BIM Proficiency Matrix includes eight categories measured against four maturity/proficiency levels. The matrix focuses on the accuracy and richness of the digital model (as an end-product) and has less focus on the process of creating that digital model. More information is available at http://bit.ly/iuBIM (last updated 28.10.2009, last checked 04.11.2009).

Maturity Level	A Data Richness	B Life-cycle Views	C Roles Or Disciplines	G Change Management	D Business Process	F Timeliness/ Response	E Delivery Method	H Graphical Information	I Spatial Capability	J Information Accuracy	K nteroperability/ IFC Support
1	Basic Core Data	No Complete Project Phase	No Single Role Fully Supported	No CM Capability	Separate Processes Not Integrated	Most Response Info manually re-collected - Slow	Single Point Access No IA	Primarily Text - No Technical Graphics	Not Spatially Located	No Ground Truth	No Interoperability
2	Expanded Data Set	Planning & Design	Only One Role Supported	Aware of CM	Few Bus Processes Collect Info	Most Response Info manually re-collected	Single Point Access w/ Limited IA	2D Non-Intelligent As Designed	Basic Spatial Location	Initial Ground Truth	Forced Interoperability
3	Enhanced Data Set	Add Construction/ Supply	Two Roles Partially Supported	Aware of CM and Root Cause Analysis	Some Bus Process Collect Info	Data Calls Not In BIM But Most Other Data Is	Network Access w/ Basic IA	NCS 2D Non-Intelligent As Designed	Spatially Located	Limited Ground Truth - Int Spaces	Limited Interoperability
4	Data Plus Some Information	Includes Construction/ Supply	Two Roles Fully Supported	Aware CM, RCA and Feedback	Most Bus Processes Collect Info	Limited Response Info Available In BIM	Network Access w/ Full IA	NCS 2D Intelligent As Designed	Located w/ Limited Info Sharing	Full Ground Truth - Int Spaces	Limited Info Transfers Between COTS
5	Data Plus Expanded Information	Includes Constr/Supply & Fabrication	Partial Plan, Design&Constr Supported	Implementing CM	All Business Process(BP) Collect Info	Most Response Info Available In BIM	Limited Web Enabled Services	NCS 2D Intelligent As-Builts	Spatially located w/Metadata	Limited Ground Truth - Int & Ext	Most Info Transfers Between COTS
6	Data w/Limited Authoritative Information	Add Limited Operations & Warranty	Plan, Design & Construction Supported	Initial CM process implemented	Few BP Collect & Maintain Info	All Response Info Available In BIM	Full Web Enabled Services	NCS 2D Intelligent And Current	Spatially located w/Full Info Share	Full Ground Truth - Int And Ext	Full Info Transfers Between COTS
7	Data w/ Mostly Authoritative Information	Includes Operations & Warranty	Partial Ops & Sustainment Supported	CM process in place and early implementation of root cause analysis	Some BP Collect & Maintain Info	All Response Info From BIM & Timely	Full Web Enabled Services w/IA	3D - Intelligent Graphics	Part of a limited GIS	Limited Comp Areas & Ground Truth	Limited Info Uses IFC's For Interoperability
8	Completely Authoritative Information	Add Financial	Operations & Sustainment Supported	CM and RCA capability implemented and being used	All BP Collect & Maintain Info	Limited Real Time Access From BIM	Web Enabled Services - Secure	3D - Current And Intelligent	Part of a more complete GIS	Full Computed Areas & Ground Truth	Expanded Info Uses IFC's For Interoperability
9	Limited Knowledge Management	Full Facility Life-cycle Collection	All Facility Life-Cycle Roles Supported	Business processes are sustained by CM using RCA and Feedback loops	Some BP Collect&Maint In Real Time	Full Real Time Access From BIM	Netcentric SOA Based CAC Access	4D - Add Time	Integrated into a complete GIS	Comp GT w/Limited Metrics	Most Info Uses IFC's For Interoperability
10	Full Knowledge Management	Supports External Efforts	Internal and External Roles Supported	Business processes are routinely sustained by CM, RCA and Feedback loops	All BP Collect&Maint In Real Time	Real Time Access w/ Live Feeds	Netcentric SOA Role Based CAC	nD - Time & Cost	Integrated into GIS w/ Full Info Flow	Computed Ground Truth w/Full Metrics	All Info Uses IFC's For Interoperability

Figure 8. NBIMS CMM Chart (adopted from NIBS, 2007) – more readable MS Excel chart at http://bit.ly/NBIMS

NBIMS' I-CMM is based on the concept of Minimum BIM: achieving a minimum total score for maturity across 'Areas of Interest' beyond which a project is not considered 'true BIM'.

NBIM Standard, version 1 states that "one should obtain a minimum score of 20.1 in order to consider true BIM maturity". It is however noted that the minimum score for the distinction of a 'Minimum BIM' is not fixed but is "dependent on the date the interface [the I-CMM tool] is used". The minimum score thus changes[viii] yearly or "as the rhetorical bar is raised and owners demand more from the models being delivered" (NIST, 2007). Also, each of the 11 Areas of Interest used in NBIMS' CMM are weighted. This weighting scheme is not conceptually fixed but can be preferentially altered by organisations as they see fit.
NBIMS' CMM is still in its early days of development (NIST, 2007) and may yet change significantly. However, in its current form, NBIMS's CMM and the I-CMM tool suffer from structural limitations that may restrict its usefulness and usability:

- NBMIS' CMM employs ten maturity levels with minimal distinction between them. Most capability maturity models surveyed - from within and outside the AECO industry - include only four, five or six distinctive levels (refer to Table 6).
- The Areas of Interest used are not easily understood and may significantly overlap (Suermann et al., 2008) (McCuen, 2007). This may still be true even with the additional explanatory tab available within the I-CMM tool.

[viii] The minimum score changed to 30 in June, 2009 and then became 40 soon after that (last I-CMM tool checked was v1.9 - August 24, 2009).

- The variability of the 'minimum score for the Minimum BIM' will cause scoring inconsistencies. Pre-assigning the minimum score according to calendar year _and_ allowing it to be changed 'according to demands by owners' are in sharp contrast. Also, it is difficult to imagine that industry's BIM maturity will increase (or can be encouraged to increase) in a pre-defined linear fashion or that owners' BIM requirements can be established/ represented through a generic minimum score.
- The variability of scoring-weights assigned to Areas of Interest in accordance to organisational preference (or the elusive 'national consensus') – as encouraged within the NBIM Standard - will minimise the usefulness of the I-CMM tool and neutralise the 'certification' process.
- The current configuration of the I-CMM tool allows organisations/projects to accumulate high total scores even if they achieved very low scores on a number of Areas of Interest ('platinum' certification can be achieved even when a project has no Change Management or Spatial Capability).
- The NBIM's CMM Areas of Interest are only useful in assessing Models and not the teams, organisations or project-teams which generate them.
- The NBIM's CMM in both its static and dynamic versions can only be applied 'internally' through self-assessment or peer-revision.
- Most importantly, the inability of the NBIM's CMM – in its current form - to assess any BIM metric beyond 'information management' (NIST, 2007) severely limits its applicability and usefulness.

The AECO industry, challenged by the widely-reported capabilities and requirements of Building Information Modelling, will benefit from the availability of a maturity index that can assess a host of metrics across many organisational scales. The availability of such a BIM-specific maturity index will assist individuals, organisations and industry bodies to (a) justify investment in BIM competency development and productivity enhancement, (b) asses their BIM performance, strengths and weaknesses and (c) potentially gain market recognition for their BIM products and service quality.

BIM-specific Maturity Index

A BIM-specific maturity index has been developed by analysing then integrating several models from different industries. Its Maturity Levels reflect the *extent* of BIM abilities, deliverables and their requirements as opposed to *minimum* abilities reflected through Capability Stages. The BIM Maturity Index has five distinct levels: (a) Initial/ Ad-hoc, (b) Defined, (c) Managed, (d) Integrated and (e) Optimised. Level names have been chosen through comparing terminology used by many maturity models (Table 6) followed by selecting those easily understandable by AECO stakeholders and able to reflect the increasing BIM maturity from ad-hoc to continuous improvement.

Table 6. A non-exhaustive list of terminology used by CMMs to denote maturity levels including those used by the BIM Maturity Index

MATURITY LEVELS

Maturity Models	**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	Optimised
COBIT, Control Objects for Information and related Technology	Non-existent	Initial/ Ad- hoc	Repeatable but Intuitive	Defined Process	Managed & Measurable	Optimised
CMMI, Capability Maturity Model Integration (Staged Representation)		Initial	Managed	Defined	Quantitatively Managed	Optimising
CMMI (Continuous Representation)	Incomplete	Performed	Managed	Defined	Quantitatively Managed	Optimising
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	Optimising
P3M3, Portfolio, Programme and Project Management Maturity Model		Awareness	Repeatable	Defined	Managed	Optimised
$(PM)^2$, Project Management Process Maturity Model		Ad-hoc	Planned	Managed at Project Level	Managed at Corporate Level	Continuous Learning
SPICE, Standardised 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

In general, the progression from low to higher levels of maturity indicate (i) better control through minimising variations between targets and actual results, (ii) better predictability and forecasting by lowering variability in competency, performance and costs *and* (iii) greater effectiveness in reaching defined goals and setting new more ambitious ones (Lockamy III & McCormack, 2004) (Kevin McCormack, Ladeira, & Oliveira, 2008). In this chapter, it will be difficult to discuss all maturity levels pertaining to all capability stages at all organisational scales. Only one sample capability/maturity/scale combination will be generically described below. Descriptions of other maturity combinations can be gleaned from

Table.

The following is a hypothetical assessment report for an Organisation (organisational scale 9) discovered to be at Capability Stage 1 (object-based modelling) and Maturity Level a (initial/ad-hoc):

> *Summary:* the organisation is at Capability Stage 1 with Maturity Level 'a'. BIM implementation is characterised by *the absence of* an overall strategy and *a significant shortage of* defined processes and policies. BIM software tools are deployed in a non-systematic fashion and without adequate prior investigations and preparations. BIM adoption is only partially achieved through the 'heroic' efforts of individual champions – a process that lacks the active and consistent support of middle and senior management.
>
> *Technology:* Usage of software applications is unmonitored and unregulated. Software licence numbers are typically misaligned to staff requirements. 3D Models are relied upon to mainly generate accurate 2D representations/deliverables. Data usage and storage are not well defined and data exchanges suffer from a severe lack of interoperability.
> Hardware specifications are non-uniform and fall well-below staff skills and expected BIM deliverables. Equipment replacement and upgrades are treated as cost items, postponed whenever possible and committed to only when unavoidable.
> Network solutions are non-existent or ad-hoc. Individuals and teams use whatever tools available to communicate and share data. Stakeholders lack the network infrastructure necessary to harvest, store and share knowledge.
>
> *Process:* Senior leaders/managers have varied visions about BIM and its implementation is conducted without an overall strategy. As typical at this maturity level, BIM is treated as a technology stream without much consideration for its process and policy implications. Change resistance is evident among staff and possibly wide-spread amongst middle management.
> The workplace environment is not recognised as a factor in staff satisfaction/motivation and is not conducive to productivity. Knowledge is not recognised as an organisational asset and is mainly shared informally between staff - through tips, techniques and lessons learned.
> Business opportunities arising from BIM are not acknowledged. BIM objects (components, parts or families) are not consistently available in adequate numbers or quality. 3D models deliverables (as BIM products) suffer from too high, too low or inconsistent levels of detail. More importance is given to visual quality of 2D representations than is given to 3D model accuracy.
> Products and services offered by the organisation represent a fraction of the capabilities inherent within the software tools employed. There are no modelling quality checks or formal audit procedures.

BIM Projects are conducted using inconsistent practices and there are no project initiation or closure protocols. Staff competency levels are unknown to management, roles are ambiguous and team structures pre-date BIM. Staff are neither structurally trained nor inducted into BIM processes; are generally confused about workflows and 'who to go to' for technical and procedural assistance.
Performance is unpredictable and productivity depends on champions' efforts within teams. A mentality of 'shortcuts' and 'working around the system' flourishes. Performance is inconsistent and is neither monitored nor reported in any systematic fashion. In general, islands of concentrated BIM productivity are separated by seas of BIM idleness/confusion.

Policy: The organisation does not document or adopt BIM-specific guidelines and standards. There are minor or inconsistent quality controls for 3D models and 2D representation. There are no training policies, and educational mediums – when available - are not suitable or accessible to staff. Contractually, there is a dependence on pre-BIM arrangements with no BIM-specific risk identification and mitigation policies.

The above is a generic summary-description of a hypothetical organisation grappling with low BIM maturity while implementing object-based modelling. The BIM Maturity Matrix (BIm^3), introduced in the next section, is a comprehensive knowledge tool that assists individuals, organisations and other organisational scales in planning, achieving and assessing BIM performance milestones.

5 The BIM Maturity Matrix

The BIM Maturity Matrix (BIm^3) is a knowledge tool which incorporates many BIM Framework components for the purpose of performance measurement and improvement. Both its structure and content have benefited from time-tested maturity (Table 4) and excellence models (Table 5). To enable its wide applicability across the AECO industry, the BIM Maturity Matrix follows a set of guiding principles. BIm^3 has been developed to be:

- *Specific:* the Matrix is composed of a set of interlocking BIM capability stages, steps, organisational scales, maturity areas and levels. All components are well defined, complementary and serve specific purposes in assessing BIM capability and maturity.
- *Attainable:* all BIM capability stages and maturity levels can be achieved through an accumulation of defined actions.
- *Applicable:* the Maturity Matrix can be equally utilised by all AECO stakeholders across all Project Lifecycle Phases.
- *Flexible*: capability and maturity assessments can be performed across organisational scales.
- *Gradual:* the Matrix reflects and encourages smooth progression to increasingly higher capability and/or maturity.
- *Cumulative:* BIM capability stages and maturity levels, the two main components of the Matrix, are logical progressions. Deliverables from one capability stage or maturity level are prerequisites for the next stage or level.
- *Current:* the Matrix is designed around current and emerging technologies. Also, its format, dependencies and terminology have been selected to minimise the need for frequent structural changes.
- *Informative:* The Matrix provides "feedback for improvement" as well as "guidance for next steps" (Nightingale & Mize, 2002).
- *Measurable:* maturity assessments are linked to capability stages and organisational scales. This allows like-to-like comparisons without compromising units of measurement.
- *Granular:* maturity assessments can be conducted at multiple granularity levels, delivering a stepped-range of scores and reports.
- *Neutral:* the BIM Maturity Matrix does not prejudice proprietary, non-proprietary, closed, open, free or commercial solutions/ schemas. It can be employed by stakeholders irrespective of their technical persuasion.
- *Relevant:* the Matrix and its underlying concepts are relevant to both industry and academia; this should encourage its adoption and development respectively.

To meet the above guiding principles, the BIM Maturity Matrix combines several BIM Framework components represented in Figure 9 below:

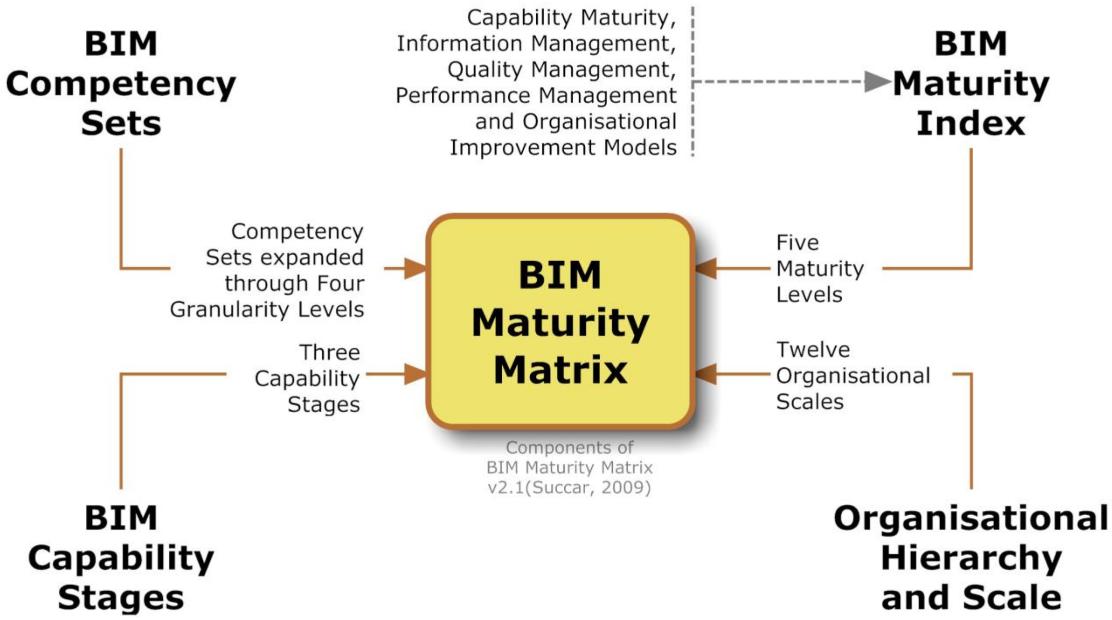


Figure 9. Components of the BIM Maturity Matrix v2.2

Sample Static Tabular Form

The BIM Maturity Matrix incorporates a set of concepts whose interactions can be represented through many static and dynamic mediums. The Matrix, in its expanded database-driven form, includes all Capability Stages, Maturity Levels and Organisational Scales.

Table 7 below introduces a static representation of the Matrix at a sample Granularity Level:

BIM MATURITY MATRIX

BIM COMPETENCY SETS		BIM Competency Areas at Granularity level 1	a INITIAL	b DEFINED	c MANAGED	d INTEGRATED	e OPTIMISED
BIM COMPETENCY SETS	TECHNOLOGY	**Software:** applications, deliverables and data	Usage of software applications is unmonitored and unregulated. 3D Models are relied on to mainly generate accurate 2D representations/deliverables. Data usage, storage and exchanges are not defined within organisations or project teams. Exchanges suffer from a severe lack of interoperability.	Software usage/introduction is unified within an organisation or project teams (multiple organisations). 3D Models are relied upon to generate 2D as well as 3D deliverables. Data usage, storage and exchange are well defined within organisations and project teams. Interoperable data exchanges are defined and prioritised.	Software selection and usage is controlled and managed according to defined deliverables. Models are the basis for 3D views, 2D representations, quantification, specification and analytical studies. Data usage, storage and exchanges are monitored and controlled. Data flow is documented and well-managed. Interoperable data exchanges are mandated and closely monitored.	Software selection and deployment follows strategic objectives, not just operational requirements. Modelling deliverables are well synchronised across projects and tightly integrated with business processes. Interoperable data usage, storage and exchange are regulated and performed as part of an overall organisational or project-team strategy.	Selection/use of software tools is continuously revisited to enhance productivity and align with strategic objectives. Modelling deliverables are cyclically being revised/ optimised to benefit from new software functionalities and available extensions. All matters related to interoperable data usage storage and exchange are documented, controlled, reflected upon and proactively enhanced.
		Hardware: equipment, deliverables and location/mobility	BIM equipment is inadequate; specifications are too low or inconsistent across the organisation. Equipment replacement or upgrades are treated as cost items and performed only when unavoidable.	Equipment specifications – suitable for the delivery of BIM products and services - are defined, budgeted-for and standardised across the organisation. Hardware replacements and upgrades are well-defined cost items.	A strategy is in place to transparently document, manage and maintain BIM equipment. Investment in hardware is well-targeted to enhance staff mobility (where needed) and extend BIM productivity.	Equipment deployments are treated as BIM enablers. Investment in equipment is tightly integrated with financial plans, business strategies and performance objectives.	Existing equipment and innovative solutions are continuously tested, upgraded and deployed. BIM hardware become part of organisation's or project team's competitive advantage.
		Network: solutions, deliverables and security/ access control	Network solutions are non-existent or ad-hoc. Individuals, organisations (single location/ dispersed) and project teams use whatever tools found to communicate and share data. Stakeholders lack the network infrastructure necessary to harvest, store and share knowledge.	Network solutions for sharing information and controlling access are identified within and between organisations. At project level, stakeholders identify their requirements for sharing data/information. Dispersed organisations and project teams are connected through relatively low-bandwidth connections.	Network solutions for harvesting, storing and sharing knowledge within and between organisations are well managed through common platforms (e.g. intranets or extranets). Content and asset management tools are deployed to regulate structured and unstructured data shared across high-bandwidth connections.	Network solutions enable multiple facets of the BIM process to be integrated through seamless real-time sharing of data, information and knowledge. Solutions include project-specific networks/portals which enable data-intensive interchange (interoperable exchange) between stakeholders.	Network solutions are continuously assessed and replaced by the latest tested innovations. Networks facilitate knowledge acquisition, storing and sharing between all stakeholders. Optimisation of integrated data , process and communication channels is relentless.

		BIM Competency Areas at Granularity level 1	a INITIAL	b DEFINED	c MANAGED	d INTEGRATED	e OPTIMISED
BIM COMPETENCY SETS	PROCESS	**Infrastructure:** physical and knowledge-related	The work environment is either not recognised as a factor in staff satisfaction or may not be conducive to productivity. Knowledge is not recognised as an asset; BIM knowledge is typically shared informally between staff (through tips, techniques and lessons learned).	The work environment and workplace tools are identified as factors affecting motivation and productivity. Similarly, knowledge is recognised as an asset; shared knowledge is harvested, documented and thus transferred from tacit to explicit.	The work environment is controlled, modified and it's criteria managed to enhance staff motivation, satisfaction and productivity. Also, documented knowledge is adequately stored.	Environmental factors are integrated into performance strategies. Knowledge is integrated into organisational systems; stored knowledge is made accessible and easily retrievable [refer to the 4 levels of knowledge retention (Arif et al., 2009)].	Physical workplace factors are reviewed constantly to insure staff satisfaction and an environment conducive to productivity. Similarly, knowledge structures responsible for acquisition, representation and dissemination are systematically reviewed and enhanced.
		Products & Services specification, differentiation, project delivery approach and R&D	3D models deliverables (a BIM product) suffer from too high, too low or inconsistent levels of detail.	A "statement defining the object breakdown of the 3D model" (Bouygues, 2007) is available.	Adoption of product/ service specifications similar to Model Progression Specifications (AIA, 2008), BIPS 'information levels' (BIPS, 2008) or similar.	Products and services are specified and differentiated according to Model Progression Specifications or similar.	BIM products and services are constantly evaluated; feedback loops promote continuous improvement.
		Human Resources: competencies, roles, experience and dynamics	There is an absence of defined processes; roles are ambiguous and team structures/dynamics are inconsistent. Performance is unpredictable and productivity depends on individual heroics. A mentality of 'working 'around the system' flourishes.	BIM roles are informally defined and teams are formed accordingly. Each BIM project is planned independently. BIM competency is identified and targeted; BIM heroism fades as competency increases but productivity is still unpredictable.	Cooperation within organisations increases as tools for cross-project communication are made available. Flow of information steadies; BIM roles are visible and targets are achieved more consistently.	BIM roles and competency targets are imbedded within the organisation. Traditional teams are replaced by BIM-oriented ones as new processes become part of organisation's / project team's culture. Productivity is now consistent and predictable.	BIM competency targets are continuously upgraded to match technological advances and align with organisational objectives. Human resource practices are proactively reviewed to insure intellectual capital matches process needs.
		Leadership: innovation and renewal, strategic, organisational, communicative and managerial attributes	Senior leaders/ managers have varied visions about BIM. BIM implementation (according to BIM Stage requirements) is conducted without a guiding strategy. At this maturity level, BIM is treated as a technology stream; innovation is not recognised as a independent value and business opportunities arising from BIM are not acknowledged.	Senior leaders/managers adopt a common vision about BIM. BIM implementation strategy lacks actionable details. BIM is treated as a process-changing, technology stream. Product and process innovations are recognised; business opportunities arising from BIM are identified but not exploited.	The vision to implement BIM is communicated and understood by most staff. BIM implementation strategy is coupled with detailed action plans and a monitoring regime. BIM is acknowledged as a series of technology, process and policy changes which need to be managed without hampering innovation. Business opportunities arising from BIM are acknowledged and used in marketing efforts.	The vision is shared by staff across the organisation and/or project partners. BIM implementation, its requirements and process/ product innovation are integrated into organisational, strategic, managerial and communicative channels. Business opportunities arising from BIM are part of team, organisation or project-team's competitive advantage and are used to attract and keep clients.	Stakeholders have internalised the BIM vision and are actively achieving it (Nightingale & Mize, 2002). BIM implementation strategy and its effects on organisational models are continuously revisited and realigned with other strategies. If alterations are needed, they are proactively implemented. Innovative product/ process solutions and business opportunities are sought-after and followed through relentlessly.

BIM COMPETENCY SETS		BIM Competency Areas at Granularity level 1	a INITIAL	b DEFINED	c MANAGED	d INTEGRATED	e OPTIMISED
	POLICY	**Regulatory**: rules/ directives, standards/ classifications, guidelines/ benchmarks and codes/ regulations	There are no BIM guidelines, documentation protocols or modelling standards. There is an absence of documentation and modelling standards. There is informal or no quality control plans; neither for 3D models nor for documentation. There are no performance benchmarks for processes, products or services.	Basic BIM guidelines are available (e.g. training manual and BIM delivery standards). Modelling and documentation standards are well defined according to market-accepted standards. Quality targets and performance benchmarks are set.	Detailed BIM guidelines are available (training, standards, workflow, exceptions...). Modelling, representation, quantification, specifications and analytical properties of 3D models are managed through detailed modelling standards and quality plans. Performance against benchmarks is tightly monitored and controlled.	BIM guidelines are integrated into overall policies and business strategies. BIM standards and performance benchmarks are incorporated into quality management and performance improvement systems.	BIM guidelines are continuously and proactively refined to reflect lessons learned and industry best practices. Quality improvement and adherence to regulations and codes are continuously aligned and refined. Benchmarks are repetitively revisited to insure highest possible quality in processes, products and services
		Contractual: responsibilities, rewards and risks	Dependence on pre-BIM contractual arrangements. BIM risks related to model-based collaboration (differ in each market) are not recognised or are ignored.	BIM requirements are recognised. "Statements defining the responsibility of each stakeholder regarding information management" (Bouygues, 2007) are now available.	There is a mechanism to manage shared BIM intellectual property, confidentiality, liability and a system for BIM conflict resolution.	Organisation are aligned through trust and mutual dependency beyond contractual barriers.	Responsibilities, risks and rewards are continuously revisited and realigned to effort. Contractual model are modified to achieve best practices and highest value for all stakeholders.
		Preparatory: research efforts/ deliverables, educational programmes/ deliverables and training programmes	Very little or no training available to BIM staff. Educational/ training mediums are not suitable to achieve the results sought.	Training requirements are defined and are typically provided only when needed. Training mediums are varied allowing flexibility in content delivery.	Training requirements are managed to adhere to pre-set broad competency and performance objectives. Training mediums are tailored to suit trainees and reach learning objectives in a cost-effective manner.	Training is integrated into organisational strategies and performance targets. Training is typically based on staff roles and respective competency objectives. Training mediums are incorporated into knowledge and communication channels.	Training is continuously evaluated and improved upon. Training availability and delivery methods are tailored to allow multi-modal continuous learning.

			a	b	c	d	e
			INITIAL	**DEFINED**	**MANAGED**	**INTEGRATED**	**OPTIMISED**
BIM CAPABILTY STGAES	**STAGE 1**	**Object-based Modelling**: single-disciplinary use within a Project Lifecycle Phase	Implementation of an object-based tool. No process or policy changes identified to accompany this implementation.	Pilot projects are concluded. BIM process and policy requirements are identified. Implementation strategy and detailed plans are prepared.	BIM processes and policies are instigated, standardised and controlled.	BIM technologies, processes and policies are integrated into organisational strategies and aligned with business objectives.	BIM technologies, processes and policies are continuously revisited to benefit from innovation and achieve higher performance targets.
	STAGE 2	**Modelling-based Collaboration**: multi-disciplinary, fast-tracked interchange of models	Ad-hoc BIM collaboration; in-house collaboration capabilities incompatible with project partners. Trust and respect between project participants may be lacking.	Single-thread, well-defined yet reactive BIM collaboration. There are identifiable signs of mutual trust and respect among project participants.	Multi-thread proactive collaboration; protocols are well documented and managed. There are mutual trust, respect and sharing of risks and rewards among project participants.	Multi-thread collaboration includes downstream players. This is characterised by the involvement of key participants during projects' early lifecycle phases.	Multi-thread team included all key players in an environment characterised by goodwill, trust and respect.
	STAGE 3	**Network-based Integration**: concurrent interdisciplinary interchange of nD models across Project Lifecycle Phases	Integrated models are generated by a limited set of project stakeholders - possibly behind corporate firewalls. Integration occurs with little or no pre-defined process guides, standards or interchange protocols. There is no formal resolution of stakeholders' roles and responsibilities.	Integrated models are generated by a large subset of project stakeholders. Integration follows predefined process guides, standards and interchange protocols. Responsibilities are distributed and risks are mitigated through contractual means.	Integrated models (or parts of) are generated and managed by most project stakeholders. Responsibilities are clear within temporary project alliances or longer-term partnerships. Risks and rewards are actively managed and distributed.	Integrated models are generated and managed by all key project stakeholders. Network-based integration is the norm and focus is no longer on *how* to integrate models/ workflows but on proactively detecting and resolving technology, process and policy misalignments.	Integration of models and workflows are continuously revisited and optimised. New efficiencies, deliverables and alignments are actively pursued by a tightly-knit interdisciplinary project team. Integrated models are contributed to by many stakeholders along the construction supply chain.
ORGANISATIONAL SCALES	**MICRO**	**Organisations:** dynamics and BIM deliverables	BIM leadership is non-existent; implementation depends on technology champions.	BIM leadership is formalised; different roles within the implementation process are defined.	Pre-defined BIM roles complement each other in managing the implementation process.	BIM roles are integrated into organisation's leadership structures.	BIM leadership continuously mutates to allow for new technologies, processes and deliverables.
	MESO	**Project Teams** (multiple organisations): inter-organisational dynamics and BIM deliverables	Each project is run independently. There is no agreement between stakeholders to collaborate beyond their current common project.	Stakeholders think beyond a single project. Collaboration protocols between project stakeholders are defined and documented.	Collaboration between multiple organisations over several projects is managed through temporary alliances between stakeholders.	Collaborative projects are undertaken by inter-disciplinary organisations or multidisciplinary project teams; an alliance of many key stakeholders.	Collaborative projects are undertaken by self-optimising interdisciplinary project teams which include most stakeholders.
	MACRO	**Markets:** dynamics and BIM deliverables	Very few supplier-generated BIM components (virtual products and materials representing physical ones). Most components are prepared by software developers and end-users.	Supplier-generated BIM components are increasingly available as manufactures/ suppliers identify the business benefits.	BIM Components are available through highly accessible/searchable central repositories. Components are not interactively connected to suppliers' databases.	Access to component repositories is integrated into BIM software. Components are interactively linked to source databases (for price, availability, etc...).	Dynamic, multi-way generation and interchange of BIM components (virtual products and materials) between all project stakeholders through central or meshed repositories.

Table 7. Building Information Modelling Maturity Matrix – static tabular guide at sample granularity, v1.1

6 Granularity of Competency Sets and Areas

Competency Sets include a large number of individual competencies grouped under numerous competency headings (refer to Figure 5). To enhance capability and maturity assessments and to increase their flexibility, a Granularity 'Filter' (Succar, 2009) with four Granularity Levels (GLevels) has been developed. Progression from low to higher levels of granularity indicates an increase in (i) assessment breadth, (ii) scoring detail, (iv) formality *and* (iv) assessor specialisation.

Using high-granularity levels (GLevels 3 or 4) exposes more detailed Competency Areas than low-granularity levels (GLevels 1 or 2). This variability in breadth, detail, formality and specialisation 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 8 below provides more information about the four Granularity Levels:

Table 8. BIM Competency Granularity Filter

COMPETENCY GRANULARITY FILTER

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**	The most comprehensive appraisal...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 customisable, 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 & 11	Self, Peer and External Consultant	Audit Report *BIMC&M Auditing Guide*

The mind map depicted in Section 2 identifies thirty-four Competency Areas available at GLevel 2 (Evaluation) as compared to only ten areas available at GLevel 1 (Discovery). Figure 10 below explores BIM Competencies at GLevel 3 (Certification) and GLevel 4 (Auditing):

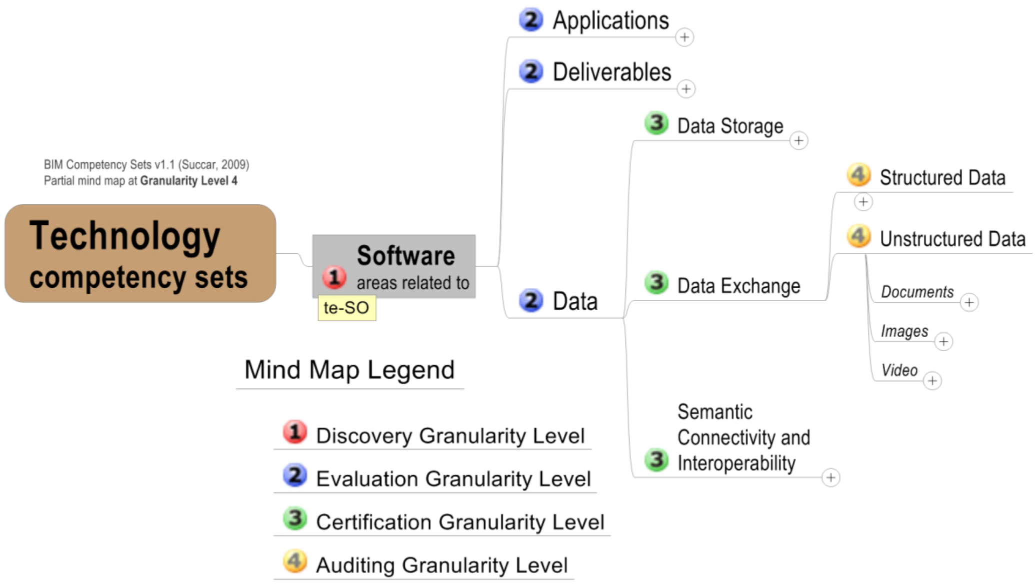


Figure 10. Competency Areas at Granularity Level 4 – partial mind map v1.1

As depicted above, the number and specificity of BIM Competencies increase dramatically at higher GLevels unveiling granular Areas like Data Storage, Data Exchange and Semantic Connectivity (at GLevel 3) and Structured and Unstructured Data (at GLevel 4). Additional more-specific competencies (not shown) include metadata, analytical models and other computable and non-computable formats (Kong et al., 2005) (Mathes, 2004) (Fallon & Palmer, 2007).

In addition to granularity, the number of Competency Areas applicable to teams and organisations varies according to Organisational Scale and Capability Stage. For example, the number of Competency Areas an 'Organisational Member' is evaluated against are less than that of a 'Project Team'. Similarly, the number of Competency Areas available for assessment within a Collaborative BIM project (BIM Stage 2) is less than that available within an Integrated one (BIM Stage 3). This variability is represented in Figure 11 below:

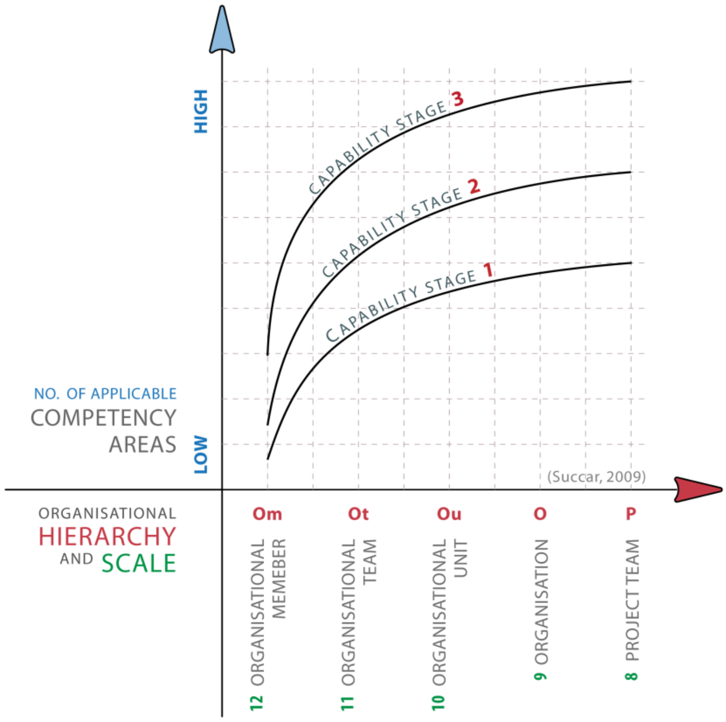


Figure 11. Applicability of Competency Areas relative to Organisational Scale and Capability Stage – diagram covering MICRO and MESO Organisational Scales v1.1

Assessment Workflow and Reporting

BIM Capability and Maturity assessments can be employed at either one of three Capability Stages (Table 2), one of twelve Organisational Scales (Table 3) and at one of four Competency Granularity Levels (Table 8). To manage all these assessment and reporting configurations, a simple assessment and reporting workflow has been developed (Figure 12):

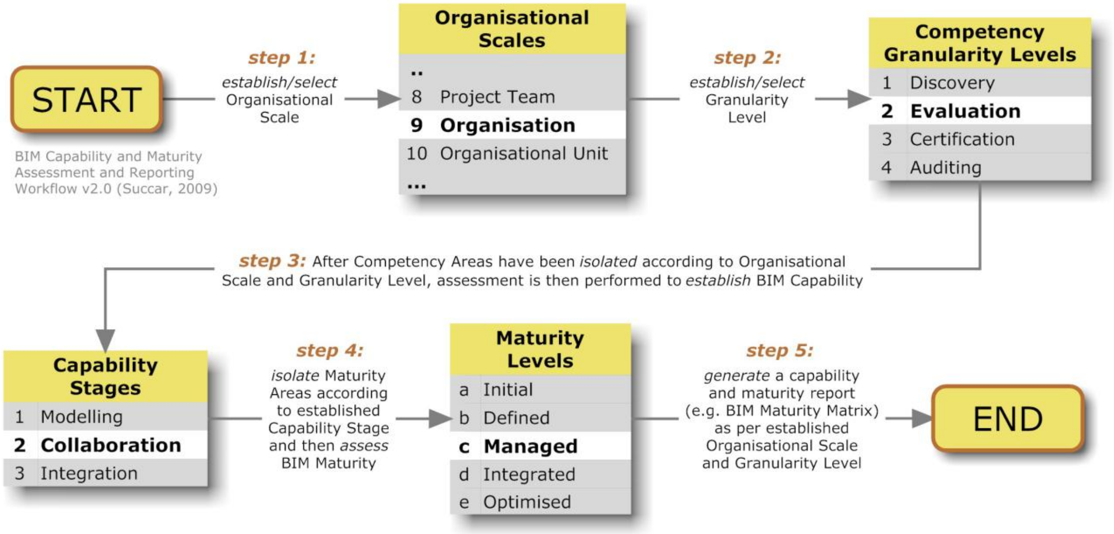


Figure 12. BIM Capability and Maturity Assessment and Reporting Workflow Diagram - v2.0

Expanding on the above diagram, a total of five workflow steps is needed to conduct a BIM Capability and Maturity Assessment. Starting with an extensive pool of generic BIM Competencies - applicable across AECO disciplines and organisational sizes – assessors first filter out non-applicable Competency Sets, conduct a series of assessments based on remaining Competency Areas and then generate a suitable Assessment Report:

Workflow Step 1: The assessor establishes the Organisational Scale (OScale) of the assessed. For example, an organisation with multiple offices across different cities may decide to assess BIM Capability and Maturity across the whole Organisation or within one specific Organisational Unit. To a varying degree (refer to Table 8), assessments can be conducted at every one of the twelve OScales. This ranges from 'Markets' (e.g. evaluating international standards and the availability of supplier-generated BIM components), through 'Project Teams' (e.g. assessing collaboration dynamics and risk-mitigation protocols within a team) to 'Organisational Members' (e.g. assessing BIM competencies of an individual architect or engineer). In this first workflow step, the selection/application of an OScale filter considerably reduces the number of applicable competencies.

Workflow Step 2: The assessor establishes assessment' Granularity Level (GLevel). There are up to four GLevels which can apply according to established OScale (refer to Table 8). Once a GLevel is set, non-applicable and more granular Competency Areas are removed from the assessment pool.

Workflow Step 3: After the number of applicable BIM Competencies has been significantly reduced by OScale and GLevel filters, the assessor establishes the 'actual' and the 'target' BIM Capability Stages. For example, if the assessed organisation – an architectural firm - has object-based modelling capability and aims to start collaborating with a structural engineer *then* BIM Stage 1 is the 'actual stage' while BIM Stage 2 is the 'target stage'. Armed with this knowledge, the assessor isolates Capability Sets A and B (refer to Figure 6) for focused capability assessment. The assessor then establishes wether each of the remaining applicable competencies has reached 'minimum capability'.

Workflow Step 4: The assessor isolates the BIM Competencies which reached 'minimum capability' and then assesses their maturity. Using the same example from workflow step 2, the assessor focuses his/her attention on Competency Sets A and B and then assess them individually against the five Maturity Levels.

Workflow Step 5: In the last workflow step, assessment results are reported using a template matching previously established OScale and GLevel. As per table 8, there are four types of assessment reports which vary in formality, coverage, detail and the provision of a named or numerical score.

Assessment Representation

Maturity assessments can be extensive in nature and may generate a significant amount of information that needs to be understood and acted upon. Knowledge visualisations can be employed to 'abstract' the BIM assessment deliverables and control their complexity by removing unnecessary detail (Kao & Archer, 1997). They are also instrumental in facilitating knowledge transfer to others (Eppler & Burkhard, 2005) as well as measuring BIM capability/ maturity against set visual benchmarks.
In addition to textual (e.g. the static BIM Maturity Matrix depicted in Section 4), assessments can be delivered in graphical (e.g. data-driven charts), multimedia (e.g. scenario-based online assessments) or through other types of knowledge visualisations (See example - Figure 13). These graphical representations allow visual comparisons between organisations or against an industry-wide average. They can also be used to help explain seemingly complex assessment results and promote action by teams and organisations.

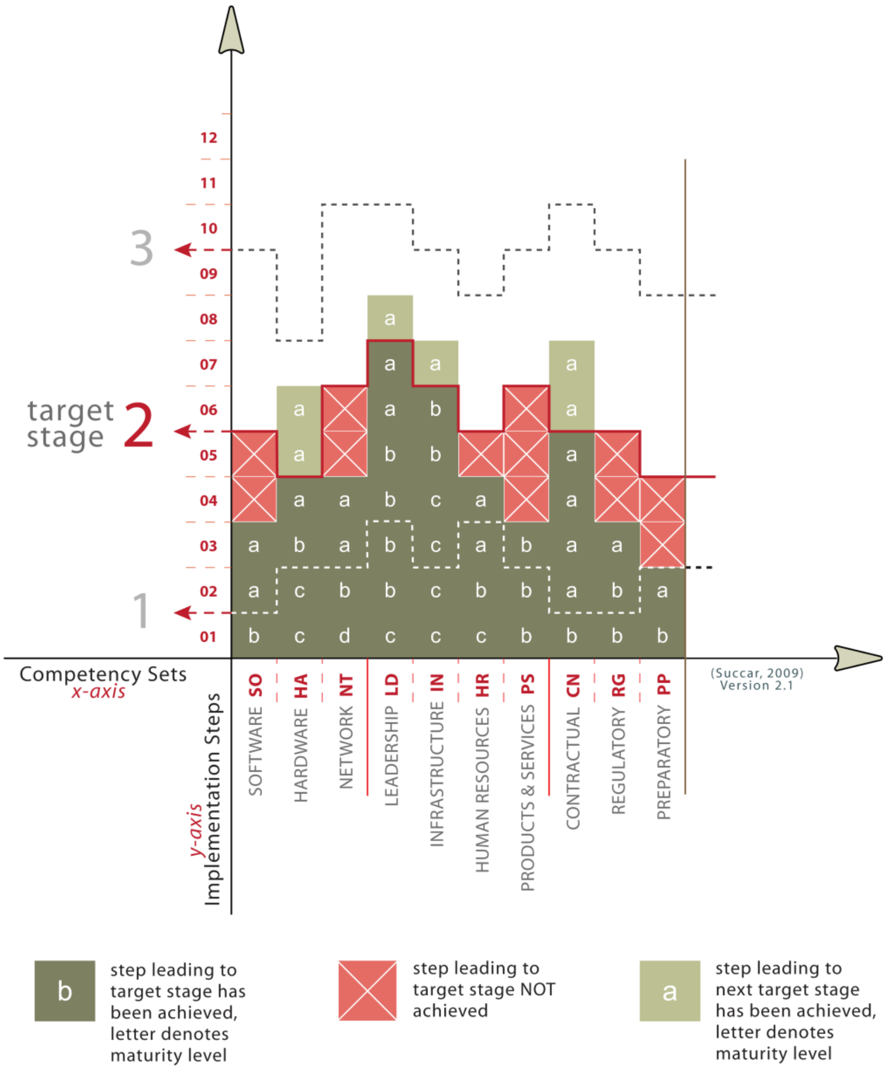


Figure 13. Visual Report of a hypothetical BIM Capability and Maturity assessment – v2.0

Sample Maturity Scoring System

Measuring BIM Capability and Maturity across markets, disciplines and organisational sizes requires an extensive, consistent yet flexible scoring system. Below is an exploration of the simplest form of scoring – called Maturity Discovery Score – to be used for informal, self-administered assessments at any Organisational Scale. The Discovery scoring system follows a simple arithmetic model:

- There are twelve individual scores relating to ten Competency Areas, one Capability Stage and one Organisational Scale.
- Maturity Levels are assigned a fixed number of maturity points: Level a (10 points), Level b (20 points), Level c (30 points), Level d (40 points) and Level e (50 points).
- The Maturity Discovery Score is the *average of* total points subdivided by twelve.

Table 9 below provides a hypothetical Maturity Discovery Score of an assessed organisation at BIM Capability Stage 2:

Table 9. Maturity Discovery Score - hypothetical maturity assessment at Granularity Level 1

MATURITY DISCOVERY SCORE

BIM Maturity Matrix Assessment at Granularity Level 1		a 10 Pts	b 20 Pts	c 30 Pts	d 40 Pts	e 50 Pts
Technology	Software			●		
	Hardware	●				
	Network		●			
Process	Leadership				●	
	Human Resources			●		
	Infrastructure		●			
	Products & Services		●			
Policy	Contractual		●			
	Regulatory			●		
	Preparatory				●	
Stage	Collaboration [2]			●		
Scale	Organisation [9]		●			
Subtotal		**10**	**100**	**120**	**80**	**0**
Total Points						**310**
Maturity Score						**25.83**
NOT SUITABLE FOR CERTIFICATION						

7 A Final Note

The BIM Maturity Matrix builds upon the BIM Framework (Succar, 2009) which identifies BIM Fields, Stages, Lenses, Steps, Project Lifecycle Phases and a specialised conceptual Ontology. This chapter further extends the Framework by developing a BIM Maturity Index, an Organisational Hierarchy/Scale and a Competency Granularity Filter. It also introduces the BIM Maturity Matrix, a Capability and Maturity assessment and reporting tool that utilizes all the above components.

The availability of an extended BIM Maturity Matrix (especially in a database-driven web format) will be beneficial to construction industry stakeholders irrespective of their Design, Construction or Operations' role. Industry practitioners can employ the Matrix and its underlying BIM Framework to:

- Increase their capability across a pre-identified range of technology, process and policy steps. As these competencies mature, they typically "meet an organisation's functional and quality expectations" (Jaco, 2004), get 'institutionalised' through standards, and organisational structures (McCormack and Johnson 2000) and help teams and organisations achieve *consistency in capability* (Vaidyanathan & Howell, 2007).
- Accurately assess their own, their peers' and potential project-partners' capability and maturity at selective organisational scales and granularity levels.
- Work towards a BIM 'performance excellence award', a BIM 'maturity certificate' or similar. Such awards are potentially beneficial for product/service differentiation as well as market positioning.
- Continuously assess and improve their BIM performance.

The BIM Maturity Matrix and its underlying BIM Framework are still being developed and extended. Future deliverables include a web-based interactive tool suitable for low-granularity, self-administered maturity assessment. Capability and maturity templates, questionnaires, guides, knowledge models and granular scoring systems are also being researched, developed and tested.

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KEY TERMS AND DEFINITIONS

BIM Fields

BIM Fields are conceptual clusters of domain players interacting and overlapping within the AECO industry. There are three BIM Field Types (Technology, Process and Policy) and three Field Components (Players, Requirements and Deliverables).

BIM Capability Stages

BIM Capability is the basic ability to perform a task, deliver a service or generate a product. BIM Capability Stages define the major milestones to be achieved by teams and organisations as they adopt BIM technologies and concepts. BIM Stages are defined by their *minimum requirements*.

BIM Lenses

BIM Lenses are distinctive layers of analysis which allow the researchers to selectively focus on any aspect of the AECO industry and generate knowledge views that either (a) highlight observables which meet the research criteria or (b) filter out those that do not.

BIM Steps

BIM Steps are the evolutionary or incremental steps that need to be completed to reach or progress within a BIM Stage (also see BIM Competency Sets below).

BIM Competency Sets

A BIM Competency Set is a hierarchical collection of individual competencies identified for the purposes of BIM implementation and assessment. If BIM Competencies are used for the purposes of active implementation, they are referred to as BIM Steps. However, if used for assessing existing implementations, they are referred to as BIM Areas.

BIM Organisational Scales

The BIM Organisational Scale is a hierarchical subdivision of markets, industries, project teams and organisations for the purpose of BIM capability and maturity measurement.

BIM Maturity Index

The term 'BIM maturity' refers to the *quality, repeatability and degrees of excellence* within a BIM capability. As opposed to 'capability' which denotes a *minimum ability*, maturity denotes the *extent of that ability*. The BIM Maturity Index (BIMMI) is a process improvement framework – with five distinct levels - developed to assess the maturity of BIM players, their requirements and deliverables across organisational scales.

BIM Maturity Matrix

The BIM Maturity Matrix (BIm^3) is a performance assessment and improvement tool which incorporates BIM Stages, Competency Sets, Organisational Scales and Granularity Levels.