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An integrated approach to BIM competency assessment, acquisition and application

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ABSTRACT

Professional, organisational and educational institutions have started to adopt BIM software tools and adapt their existing delivery systems to satisfy evolving market requirements. To enable individuals within these organisations to develop their BIM abilities, it is important to identify the BIM competencies that need to be learned, applied on the job, and measured for the purposes of performance improvement. Expanding upon previous research, this paper focuses on *individual BIM competencies*, the building blocks of organisational capability. The paper first introduces several taxonomies and conceptual models to clarify how individual competencies may be *filtered*, *classified*, and *aggregated into a seed competency inventory*. Competency items are then fed into a specialised *knowledge engine* to generate flexible assessment tools, learning modules and process workflows. Finally, the paper discusses the many benefits this competency-based approach brings to industry and academia, and explores future conceptual and tool development efforts to enable industry-wide BIM performance assessment and improvement.

1. Introduction

Individual competencies are the fundamental building blocks of organisational competency. As such they represent a common set of standards that can be used for human resource planning, management, and development [52,57,35]. Individual competencies are crucial for managing the performance of an organisation [22], and according to Sanchez and Levine [76], the "same set of competencies normally cuts across jobs and layers of the organisation" and thus can be identified and analysed irrespective of organisational departments and units.

Recent efforts to identify individual competencies within the construction industry have focused on design [16], maintenance management [13], and construction project management [19]. These investigations and our previous research on BIM capability maturity [81,84], highlight the need for a comprehensive approach that identifies, classifies and maintains an inventory of generic BIM competencies *required for* modelling, collaboration and integration activities and *applicable across* project lifecycles, industry sectors, disciplines and specialities.

Identifying and then organizing generic competencies will not only facilitate BIM adoption but will also clarify the complex activities undertaken during multidisciplinary collaboration. Many of these activities (e.g. model interchange) require input from different project participants in a mutually interdependent manner. This mutual interdependence [85] is the "most costly way to coordinate, since the people performing the work need to communicate frequently and make mutual adjustments during task execution" ([51], page 514). To reduce the costs and inefficiencies of such mutual adjustments, Lavikka et al. ([51], page 519) strongly recommends task standardisation through defining "both the independently performed work tasks and the reciprocally interdependent tasks". Standardising and thus clarifying how BIM competencies are defined and organized should contribute significantly to reducing inefficient interdependencies between teams and organisations.

Previous research conducted by the authors has focused on organisational BIM capability and maturity. Several taxonomies and models were generated to clarify performance benchmarks including a multi-stage BIM capability model, a 5-level BIM maturity index and a 12-scale organisational hierarchy [80,81]. BIM competency sets – as applicable to organisations and teams – were also identified to enable BIM performance assessment and improvement [82,83]. Given that organisational capability/maturity and individual competency are interrelated and *can be combined* to analyse performance [32], it is first important to identify the different units of analysis at which competency can be assessed and suitably analysed.

2. Individuals as agents

The competency of *individual* actors within an organisational setting is the fundamental blocks of an *organisation*'s capability [52,23]. While the term *individual* represents intelligent human actors capable of coordinating defined processes with each other ([30] — page 19), the term *organisation* is less clearly delineated and is subject to intense theoretical debate [4]. Through metaphors, Morgan [64] describes organisations as machines; organisms; brains; cultures;

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political systems; psychic prisons; flux and transformation; and instruments of domination. Each of these metaphors includes its own characterisation of individual roles and their relationships with the organisation. In addition to metaphors, organisations can also be defined in terms of goals, roles and their dependencies [29] where individuals' roles are understood as a reflection of organisational goals.

In this paper, an organisation is defined as a "structural relationship between a collection of agents" ([27] — page 129). We see organisations as multi-agent systems where "the characteristics of the whole (the organisation) are defined in terms of the characteristics of the parts (e.g. persons), while the characteristics of the whole in turn influence the characteristics of the parts" ([30] — page 19). As an *assemblage of agents* (both human and non-human) and their interactions [30,43], an organisation includes "actors, responsibilities, dependencies, social structures, organisational entities, objectives, tasks and resources" ([29] — page 10).

An organisation's capability as a multi-agent system can thus be understood through the capabilities of its agents. The individual competencies of human agents, acting interdependently to achieve *coordinated goals* ([28] — page 2) thus not only mirrors the characteristics of the human agents themselves but also reflects the capability of the organisation within which these agents interact.

Through this understanding of individuals, organisations and their relationship, the next section delineates individual competencies and introduces a structure for their identification, classification and analysis.

2.1. Competency units of analysis

An individual is the basic or primary 'unit of analysis' in understanding organisational performance [52,86]. However, there are other *units* that can be analysed to identify and predict organisational performance. These units are presented below but are preceded by definitions of a number of terms that are often used interchangeably:

A. Competency, capability and maturity
Competency refers to an *individual's ability* to perform a specific task or deliver a measureable outcome. Both capability and maturity refer to *organisational abilities* across *organisational scales* [81]: capability denotes the *minimum ability* in performing a task or delivering a measureable outcome; maturity denotes the quality, repeatability and degree of excellence within a capability.

B. Groups and teams
A *group*, as a unit of competency analysis, is a *cluster of individuals* not bound together by a project or a set of performance goals [46]. Their performance is 'additive, the sum of individual work contributions' ([68] — page 328). Committees, communities of practice, councils and ad-hoc assemblies of people are good examples of groups. A *team* is a purposeful collective of individuals "who exist to perform organisationally relevant tasks, share one or more common goals, interact socially, exhibit task interdependencies, maintain and manage boundaries, and are embedded in an organisational context…" ([48, page 6] as mentioned in [59]). Team performance is 'synergistic, the product of inter-activity among the roles' ([68] — page 328). For the purposes of this research, we have extended the term 'team' to include – in addition to individuals – a *purposeful cluster* of organisations, temporarily bound together through a unifying long-term mission or a common goal/outcome.

These distinctions allow the introduction of several *units of analysis*, each with its own measure of competency/capability:

1. Individual competency is the unit measure of an individual's ability to conduct an activity and deliver an outcome. Individual competency applies to a *single person* irrespective of role, position or employment status;
2. Group competency is the arithmetic sum of several individual competencies but – as a measure – does not reflect the efficiencies gained or lost from such an aggregation;
3. Organisational capability is the unit measure of an organisation's ability and its sub-organisational units (branches, departments, business streams, etc.); and
4. Team capability is the unit measure of team members' combined abilities. As opposed to group competency, team capability reflects the routines and dynamics [74,37] of aggregation (e.g. team compatibility, communication and collaboration). There are at least[1] three sub-units of team capability.
    4.1. Work team capability applies to a purposeful group of individuals working together to deliver a project/outcome *within* an organisation or an organisational unit;
    4.2. Project team capability applies to a purposeful group of individuals working together to deliver a project/outcome *across* two or more organisations; and
    4.3. Organisational team capability applies to two or more organisations working together (through partnering, alliancing, etc.) to pursue a common mission or deliver a common project/outcome.

These competency units and sub-units are complementary and can be flexibly used to isolate, or aggregate, the abilities of individuals and organisations. Fig. 1 and Table 1 clarify the interdependent relationship between these units of analysis.

The units of analysis shown in Fig. 1 and Table 1 provide examples of the granularity of organisational performance. As noted by Dainty et al. [19], Kakabadase [45] states that there is a demonstrable link between the competency of team members and the overall performance of an organisation. Also, Salvato [73] has shown how the evolution of organisational capability is influenced by the 'ordinary' work activities of individuals within it.

Organisations do not typically assign work activities directly to an individual but to a team. However, a team is composed of individuals and to develop a team's capability each team member needs to "be developed so that they can contribute critical capabilities to the team. This requires the identification of the critical skills that are needed to make the team effective and the development of a learning program for individuals so that they can contribute to their team's effectiveness" ([52], page 8). Competency provides a "starting point to bridge individual and organisational levels of analysis" ([74] — page 474). To establish organisational performance, it is therefore important to establish the performance of individuals who, in turn, form teams. How individual competencies, as a measure of individual performance, are defined will underpin the performance assessment and improvement of all other units of analysis.

2.2. Individual competency — definitions

It is important to first acknowledge that there is no consensus among researchers on the meaning of the term *competency* [89,77,35]. According to Ley and Albert [53], "although competencies have been considered increasingly important in HR and KM approaches, it is thus far an unresolved issue of what exactly competencies are". Table 2 explores some of the different meanings attributed to the term competency/competencies[2] as applied to individuals within an organisational context.

[1] There are other types of teams that can be identified for the purposes of competency analysis similar to role teams (e.g. managerial team), activity teams (e.g. digging team) and recreational teams (e.g. a company' sports' team). However, only the three identified sub-units are of direct relevance to this research.

[2] This paper steers away from the semantic separation between competency/competence and competencies/competences [89,77,75].

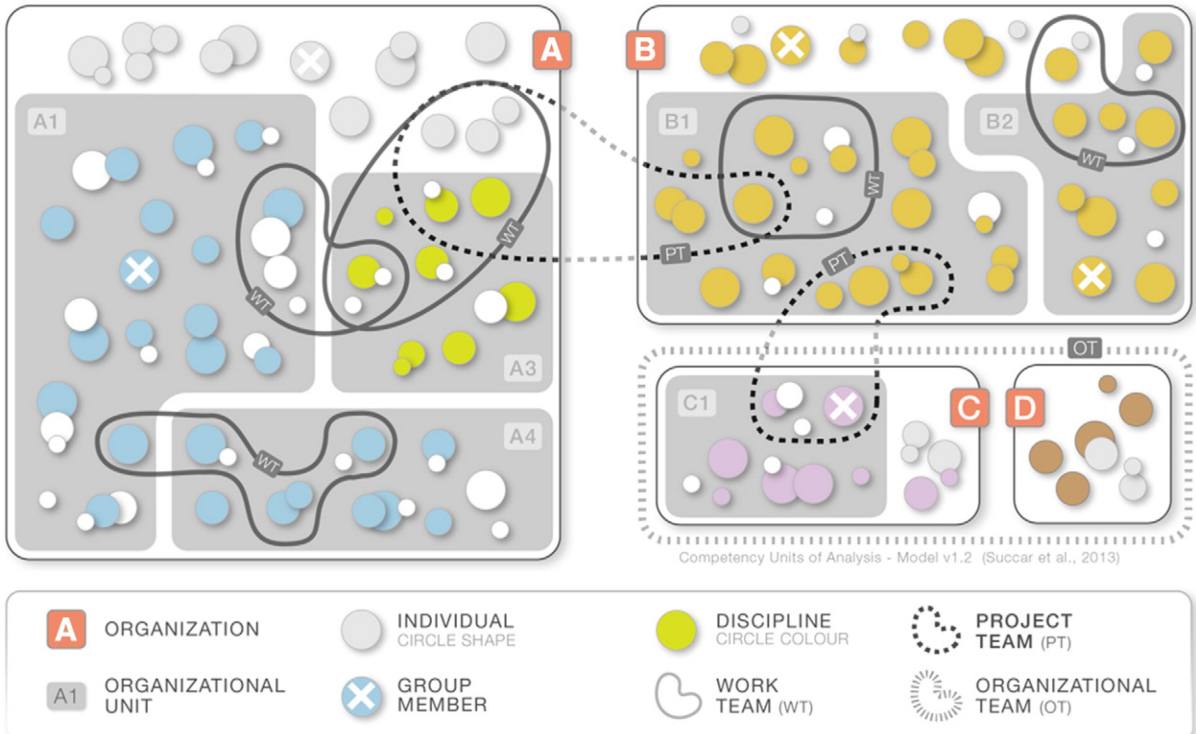

Fig. 1. Units of analysis — knowledge model identifying the units and sub-units.

Table 2 provides some of the many definitions published in academic and industrial literature. The variety of definitions reflects a multitude of meanings which – although not perfectly aligned – complement each other. To allow an integrated definition of individual BIM competency to be developed, custom classifications have been used to deconstruct the term competency. These will be re-assembled later to facilitate the classification of BIM competencies, the development of a BIM competency inventory and the introduction of a conceptual model for assessing, acquiring and applying BIM competencies.

2.3. Competency approaches

Table 2 reveals two general and complementary approaches to understanding the term competency when applied to individuals. The first approach identifies competency as an aggregation of *underlying, inner human qualities* leading to observable performance outcomes. This reflects the traditional understanding of competency prevalent within the fields of human resource management and skill/competency management — an understanding influenced by a long tradition in the field of psychology [53,60]. The second approach focuses less on personal traits and more on an individual's *professional* and *technical capabilities* as a measure to predict future performance. A competency is thus a combination of knowledge, skill and experience required to fulfil a specific task [67,88].

2.4. Competency components

Competency may be understood by analysing its component parts; the active ingredients that act in unison to deliver a measureable outcome yet can be isolated for focused inspection. As can be deduced from Table 2, an individual's abilities are the *aggregate sum of three components* — knowledge, skill and personal traits:

A. Knowledge: conceptual or theoretical knowledge [87];
B. Skill: procedural or applied knowledge [20]; and
C. Personal traits: the "other deployment-related characteristic (e.g. attitude, behaviour, physical ability)" ([38], page 5).

Competency components are complementary and may be used to define individual competencies. The relative significance of the three components/ingredients is not constant but varies to reflect the unique requirements of each measurable competency. For example, some individual competencies are based on substantial conceptual knowledge; while others are based on substantial practical skill. Some competencies require specific personal traits (including friendliness, empathy, dedication…) while other competencies may not require the same traits.

2.5. Competency manifestations

In applying the term competency to *describe*, *assess* and *predict* individual performance, three different competency manifestations can be isolated. These are as follows:

A. An individual competency as an *ability* – inert or learned – required to perform a defined activity or deliver a measureable outcome. This is exemplified in role definitions and position descriptions in advertisements which include a set of competencies *expressed as abilities or requirements*.
B. Individual competency as an *activity* – a set of tasks – performed for the purpose of delivering a measureable outcome. A step-by-step guide is a typical example of competencies *expressed as activities*; where individuals demonstrate their abilities by fulfilling an activity or a task.
C. Individual competency as an *outcome* or measureable deliverable — be it a product or a service. Learning outcomes from formal education or structured training are examples of competencies *expressed as outcomes or deliverables*.

As an example of a competency consistently applicable across the three manifestations, "using a 3D model to perform thermal analysis of a space" can be expressed as (i) a measure of an individual's *ability*

Table 1
Units of analysis — matrix.

	Competency (individual abilities)	Capability (organisational abilities)	Maturity (organisational excellence)
Individual	Individual competency		
Organisational		Organisation capability	Organisational maturity
Group (ad-hoc collection of individuals)	Group competency (aggregate of individual competency)		
Work team (Purposeful cluster of individuals within an organisation)	Work team competency (Aggregate + dynamics of individual competency)		
Project team (Purposeful cluster of individuals across two or more organisations)	Project team competency (Aggregate + dynamics of individual competency)		
Organisational team (Purposeful cluster of organisations)		Org team capability (Aggregate + dynamics of organisational capability)	Org team maturity (Aggregate + dynamics of organisational maturity)

to use 3D models to perform thermal analysis; (ii) a *task/assignment* to use 3D models to perform thermal analysis; and (iii) a learning *outcome* based on education/training on how to use 3D models to perform thermal analysis.

2.6. Competency levels

An individual's competency cannot always be designated through a binary proposition (i.e. competent/incompetent) but may be better described as a continuum separating two poles: one representing *incompetence* – lack of relevant abilities – and *competence*, the abundance of relevant abilities. In between these two poles are several *competence increments* which can be used for the purposes of measurement and comparison. The Individual Competency Index (ICI) is a simplified version of the performance model developed by Benner ([9], pages 13–34) [32] and includes five distinct levels (Fig. 2):

- Level 0 (*none*) denotes a lack of competence in a specific area or topic;
- Level 1 (*basic*) denotes an understanding of fundamentals and some initial practical application;
- Level 2 (*intermediate*) denotes a solid conceptual understanding and some practical application;
- *Level 3* (advanced) denotes significant conceptual knowledge and practical experience in performing a competency to a consistently high standard; and
- Level 4 (expert) denotes extensive knowledge, refined skill and prolonged experience in performing a defined competency at the highest standard.

Table 2
Individual competency: a non-exhaustive list of available definitions.

Competencies as	Definition	Reference
Behavioural goals	Competencies are behavioural goals defined by organisational leaders – based on business strategy and organisational culture – to guide employees, achieve synergy, improve performance and generate consistent results	[42]
Capability to perform	Competency is a “combination of skills, abilities, and knowledge needed to perform a specific task”	([67], page 1)
	Competencies are a combination of tacit and explicit knowledge, behaviour and skills, that give someone the potential for effectiveness in task performance	[23]
	Competency is an “ability to perform tasks, business processes, job, core business, activities, practices applying human/physical/ICT resources (e.g. personnel knowledge, skills, attitude, as well as organisation machinery) aimed at offering products and/or services in the market”	([26], page 135)
	Competencies are those characteristics - knowledge, skills, mindsets, thought patterns, and the like-that, when used either singularly or in various combinations, result in successful performance	[24]
	A competency is “a knowledge, skill, ability, or characteristic associated with high performance on a job, such as problem solving, analytical thinking, or leadership”	([63], page 75)
	Competencies are “distinguishable elements of underlying capacities or potentials which allow job incumbents to act competently in certain situations”	[10] as translated from German by [53]
	A competency is “a specific, identifiable, definable, and measurable knowledge, skill, ability and/or other deployment-related characteristic (e.g. attitude, behaviour, physical ability) which a human resource may possess and which is necessary for, or material to, the performance of an activity within a specific business context”	([38], page 5)
	Competencies are measurable human capabilities that are required for effective work performance demands	[58]
Performance standards	Competencies are performance standards - the ability to perform to the standards required within employment	[34]
Standardized performance requirements	A competency is “a standardized requirement for an individual to properly perform a specific job and it encompasses a combination of skills, knowledge, and behaviour utilized to improve performance”	[14] as noted in ([2], page 1271)
Resources used to reach an objective	Competencies are the “effect of combining and implementing *Resources* in a specific *Context* (including physical, social, organisational, cultural and/or economical aspects) for reaching an *Objective* (or fulfilling a mission)”	([87], page 633)
A contextual expression of ability	A competency is a “way to put in practice some knowledge, know-how and also attitudes, inside a specific context”	([11], page 154)

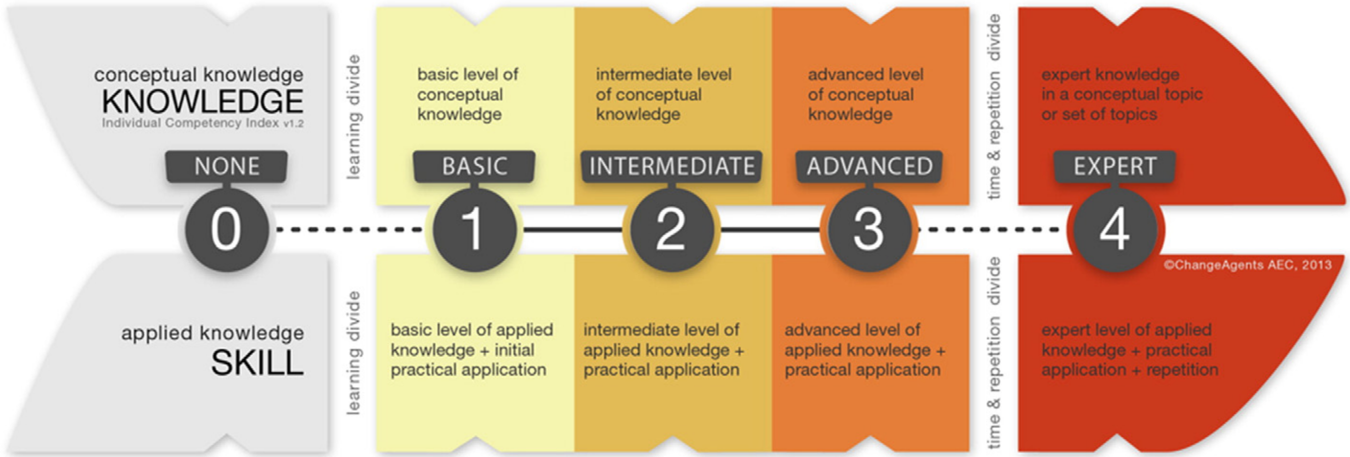

Fig. 2. The Individual Competency Index (ICI).

The ICI measures both the knowledge (conceptual knowledge) and skill (procedural knowledge) individuals require to perform a defined activity or deliver a measureable outcome. As a competency scale,[3] the ICI helps "establish the importance of a particular competency for a job, the proficiency level for each competency, and the competency level of an individual" ([63], page 76). The index also identifies two *competency divides*: the *learning divide* separating level 0 from level 1, and the *time/repetition divide* separating level 3 from level 4.

However, since ICIs only measures the abilities of *individuals* – and by extension, the aggregate abilities of a *group* of individuals – other indices are needed to establish the competencies of different organisational units. For example, BIM capability stages (Fig. 3) and BIM maturity index (Fig. 4) are sample complementary metrics which may be used to measure the BIM capability maturity of organisations, teams and other macro organisational scales [81].

3. Frequency, criticality and other competency labels

Competency frequency is a *measure of repetitiveness* and refers to "how often a competency is used in a particular job or group of jobs" ([63], page 75). Depending on the type of competency being classified, frequency can be reported in *quantitative* – e.g. three data exchanges every week – or *qualitative* terms — e.g. high frequency, medium frequency and low frequency. Competency criticality is a measure "of how important a particular competency is for a job or group of jobs" ([63], page 75). The criticality of a defined competency can be measured in *absolute* (using a 5-level Likert scale or similar) or *relative* terms (e.g. delivering learning outcome A is *less critical* than learning outcome C).

In addition to the above, there are many other criteria for classifying competencies, including autonomy, detail, evidence, specialty, complexity, context and priority. Competencies can also be classified using specialized *ontologies* [36,22] or applicable *standards* [40,39]. All these classifications can be applied *concurrently* or in *isolation* to organize competencies for use in assessment, implementation and learning systems.

[3] The ICI measures 2 out of 3 competency components (knowledge and skill). The third component (personal traits) requires specialized psychometric indices similar to Myers-Briggs [70] and RIASEC [3].

4. Individual BIM competencies

As introduced in the previous section, it is quite "impossible to arrive at a definition capable of accommodating and reconciling all the different ways that the term is used" ([89], page 12) [25]. However, we propose an *integrated definition* of individual BIM competencies which acknowledges and aligns many of these variations.

> Individual BIM competencies are the personal traits, professional knowledge and technical abilities required by an individual to perform a BIM activity or deliver a BIM-related outcome. These abilities, activities or outcomes must be measureable against performance standards and can be acquired or improved through education, training and/or development.

Some aspects of this integrated definition require clarification. These include:

1. Individual BIM competencies — these relate specifically to the *abilities of individuals* (and not to the competencies of groups, organisations or teams). Individuals can be professionals, tradespeople, academics or students from any discipline or specialty and irrespective of their position or role.
2. A BIM activity is a set of tasks directly related to procuring, generating, using, supporting and maintaining BIM-specific deliverables (as products and/or services). These deliverables typically include 3D models, documents and data required for designing, constructing and operating a facility throughout its lifecycle.
3. BIM competencies – like other competencies – *must be measureable* against performance standards. In some cases, the measurement is a simple *binary proposition*: does the ability to perform a BIM activity *exist* or *not*? In others, the measurement is a multilevel graduation: is the ability at a basic, intermediate or advanced level? Also, in some cases, competencies are objectively measured; while in others, they can only be subjectively recognized [38].
4. BIM competencies vary in their nature and *can be acquired* through equally varied means. This variety is a function of the competency itself and the individual seeking to acquire that competency. Our integrated definition does not differentiate between BIM competencies based on how they are acquired but includes competencies attained through:
   a. *Formal education* – with or without qualifications – typically focused on improving theoretical knowledge (e.g. learning design theory or how to calculate thermal gain);

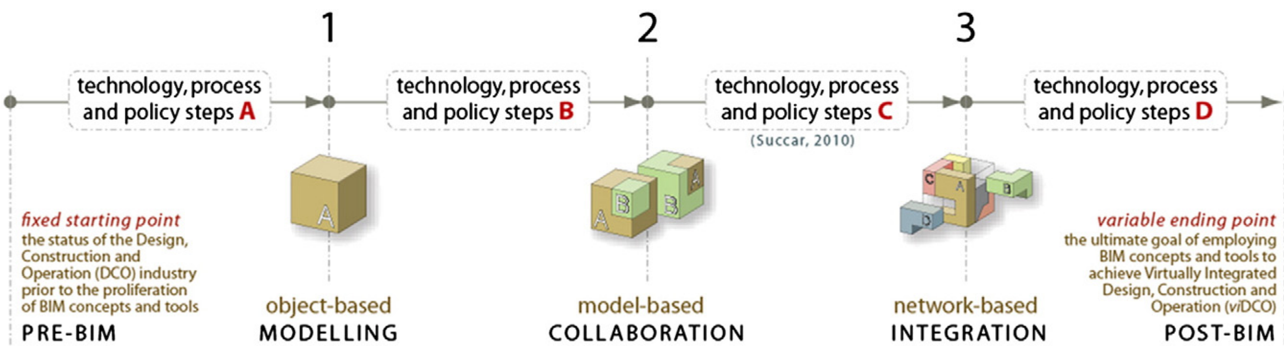

Fig. 3. BIM capability stages — shown at maturity level c.

b. *Vocational or on-the-job training* typically focused on skill improvement (e.g. how to use Autodesk Revit or operate a laser scanner); or
c. *Professional development* typically focused on improving personal traits (including self-confidence and critical thinking).

This integrated definition aligns many of the meanings attributed to the term 'competency', as reflected in Fig. 5. This illustrates the manner in which competencies may be seen to flow from *identification*, to *classification*, to *aggregation* and finally to *use*.

5. BIM competency identification

Numerous recent peer-reviewed research and industry publications have focussed on model-based deliverables and their diverse technical, procedural and regulatory criteria. With the exception of some investigations that address emerging *BIM roles* [8,7,78,66], and identify competencies related to a small number of specialties [16,13,19], comprehensive research on overall BIM competency is yet to be published.

Identifying a set of BIM-specific roles (including BIM manager, model manager and lead BIM coordinator) is a useful exercise for recruitment purposes; however, these role definitions are bound to rapidly change to reflect the relentless technological and procedural transformations from which the roles are derived.[4] Identifying the specific competency requirements of a discipline or specialty requires clarity about responsibilities. However, such an approach does not lend itself to identifying the BIM competencies common across specialties. Finally, the identification of BIM competencies specific to an organisation – the approach taken by specialist consultants – is useful for that organisation; however, it contributes little towards identifying competencies across the wider industry. A more pertinent and persistent approach would be to avoid rigid delimitation of BIM roles within arguably narrow contexts (within a specific organisation or required for a specific project) and to focus more intently on identifying industry-wide BIM competencies that shape current roles and affect emergent ones. The significance of this wider approach is amplified by the need to facilitate multidisciplinary collaboration, encourage integrated practices and workflows, and reduce inefficient interdependency [85,51] between teams and organisations.

The process of *industry-wide*, as opposed to role-, organisation-, or discipline-specific identification of BIM competencies, requires a multi-thronged approach. Competencies can be harvested from several sources: some are publically available and easily accessible, while others require much investigative and focused effort. There are several complementary ways to identify, refine and validate individual BIM competencies including:

1. Analysing 'job advertisement descriptions' crafted by recruitment sites;
2. Dissecting BIM-specific roles as defined within BIM guides, BIM management plans and similar documents;
3. Reviewing academic literature and industry publications focused on BIM workflows, deliverables and their requirements
4. Adopting and adapting formal skill inventories, competency pools, and accreditation criteria similar to those described by HR-XML-Consortium [38]; and
5. Harvesting competency requirements from industry associations, organisations and subject matter experts through interviews, focus groups and dedicated surveys.

In summary, there are many available resources, established methods and accessible means of identifying BIM competencies across the DCO industry. Through these multiple sources, BIM competencies can be *collected at an industrial scale*,[5] *conceptually filtered*[6] to isolate those which satisfy our integrated definition, and *classified* using a specially-developed, tiered taxonomy.

6. BIM competency classification — a tiered taxonomy

The number of competencies that can be collected and would satisfy the aforementioned integrated definition can be very large. To organize BIM competencies into useable clusters, a specialized taxonomy is needed.

Taxonomies are an efficient and effective way to organize and consolidate knowledge [90]. A well-structured taxonomy allows "the meaningful clustering of experience" ([50] — page 24) and is "a means toward a number of different ends; one of these ends is providing direction and/or guidance to expansion or generalisation of knowledge" ([91] — page 216). In developing a specialized taxonomy to organize BIM competencies, we have adopted the guidelines introduced by Gregor ([33], page 619): a taxonomy is expected to be "complete and exhaustive; [includes] classes that encompass all phenomena of interest; [is based on] decision rules, [which are] simple and parsimonious to assign instances to classes; and the classes should be mutually exclusive. In addition, as taxonomies are proposed to aid human understanding, [these classes should be] easily understood and […] appear natural."

The BIM competency hierarchy (Fig. 6) is a taxonomy organizing BIM competencies into meaningful, exhaustive, and mutually-exclusive clusters [33]. This clustering is goal-driven and aims to simplify a large system by decomposing it into smaller sub-systems [62] ([63], page 75). The hierarchy has several levels: competency tiers (top level) include all BIM competencies that satisfy the integrated definition introduced earlier;

[4] Mansfield [57] estimated that the shelf life of a role (or a competency model representing a role) is likely to be two years or less. This is arguably as true today as it was in the 1990s.

[5] For an exploration of Organizational Scales, please refer to ref. [81].

[6] For a discussion on conceptual lenses and filters, please refer to ref. [80].

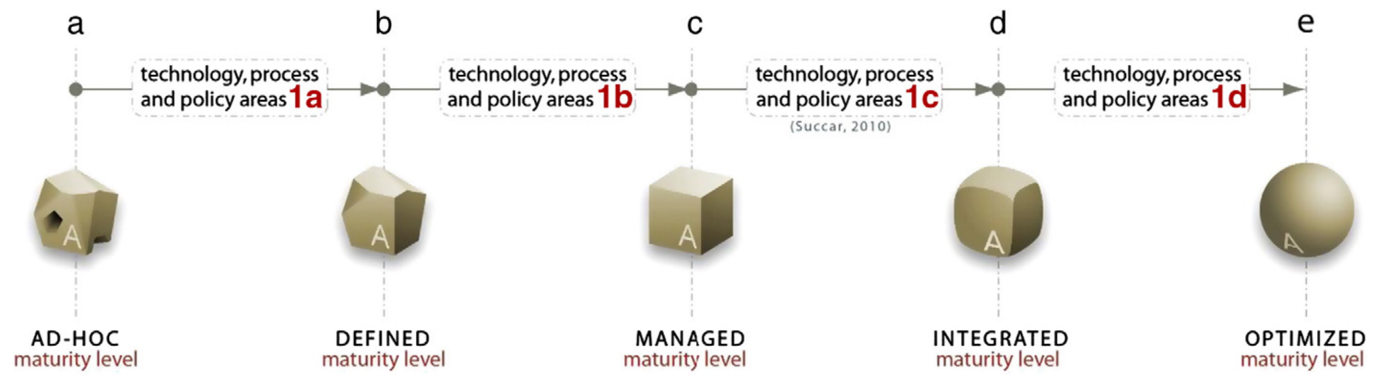

Fig. 4. The BIM Maturity Index (BIMMI) — shown at capability stage 1.

lower levels distribute competencies into competency sets and competency topics. The naming of clusters within tiers, sets and topics is based on literature and has been inferred inductively through observation and discovery [61].

Fig. 6 shows three BIM competency tiers divided into several BIM competency sets which are, in turn, subdivided into BIM competency topics. These tiers, sets, topics and their granular subdivisions (competency items) represent *all the measureable abilities, outcomes* and *activities* of individuals who deliver model-based products and services. Importantly, this representation of abilities accurately identifies an individual's competency profile using a broad spectrum of topics. It is driven by the notion that an individual cannot be recognized as either competent or incompetent *as a whole* but may be "an expert in one competency item due to their level of experience and theoretical knowledge, whilst at the same time being a novice in a competency of which they have no experience or background knowledge"([31] — page 154). Competency subdivisions are explored in detail below.

6.1. Tier 1: core competencies

The core competencies tier reflects the *personal abilities* of individuals enabling them to conduct a measureable activity or deliver a measurable outcome. This core tier is subdivided into the following four competency sets:

1. Foundational traits — personal attributes *inherent in an individual* that cannot be acquired through training or education. Foundational traits represent an individual's attitude, behaviour, motivation, and other attributes measureable through psychometric indices similar to Myers–Briggs Type Indicators [70], the RIASEC model [3] and other personality assessment systems. A natural affinity to learning new languages, or an innate ability to solve complex mathematical problems are examples of these traits;
2. Situational enablers — personal attributes related to nationality, language and other criteria which may play a *relevant* role when delivering a service or a product. For example, being of a specific nationality or having the ability to speak a certain language may be considered enablers in certain situations. Situational enablers are not absolute in nature; criteria considered relevant in one situation may be considered irrelevant in others;
3. Qualifications and licenses — personal attributes related to the *existence* or *sufficiency of* academic degrees, scientific publications, professional accreditations, trade/skill certificates or licences. Qualifications and licences are measureable and provide evidence to "substantiate the existence (sic), sufficiency, or level of a Competency" ([38], page 12); and
4. Historical indicators — attributes related to employment history, project experiences (including project types and sizes), roles played and positions held. Historical indicators provide verifiable information about past activities and indicate potential abilities in similar future situations. For example, a BIM manager's role played by an individual at an engineering company for a number of years is an indicator of specific competencies in engineering-specific BIM management.

The core competencies tier refers to *personal abilities* as opposed to 'organisational core competences'. The collective capabilities embedded within an organisation form its competitive advantage, customer value, resistance to imitation and ability to grow — as advocated by [71]. However since organisational core competence is "dependent on and inextricably intertwined with individuals' job competence" ([54] — page 436) and typically represents the "competencies everyone in a company

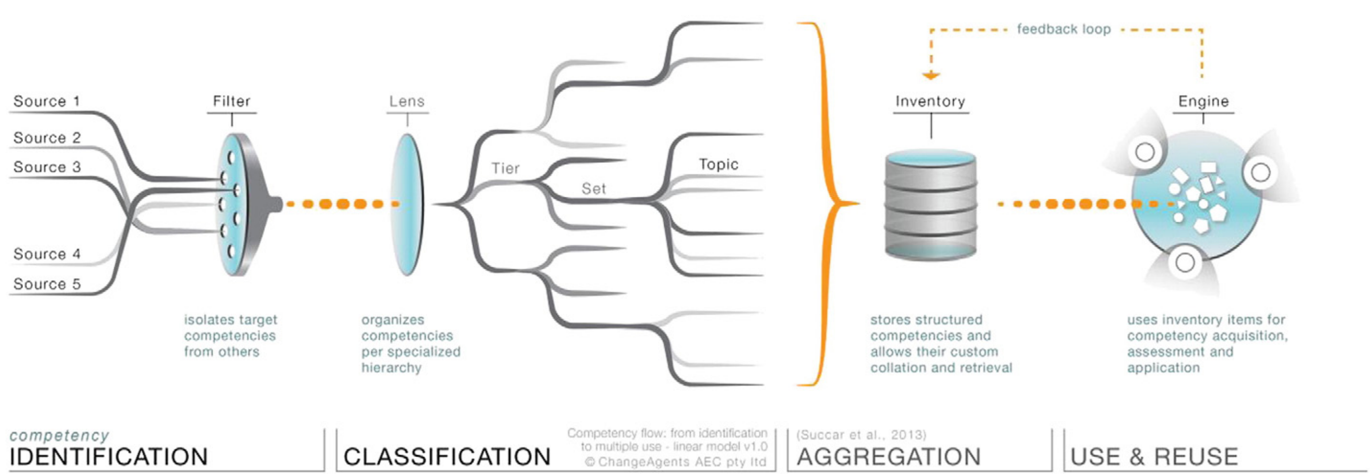

Fig. 5. Competency flow: from identification to multiple use.

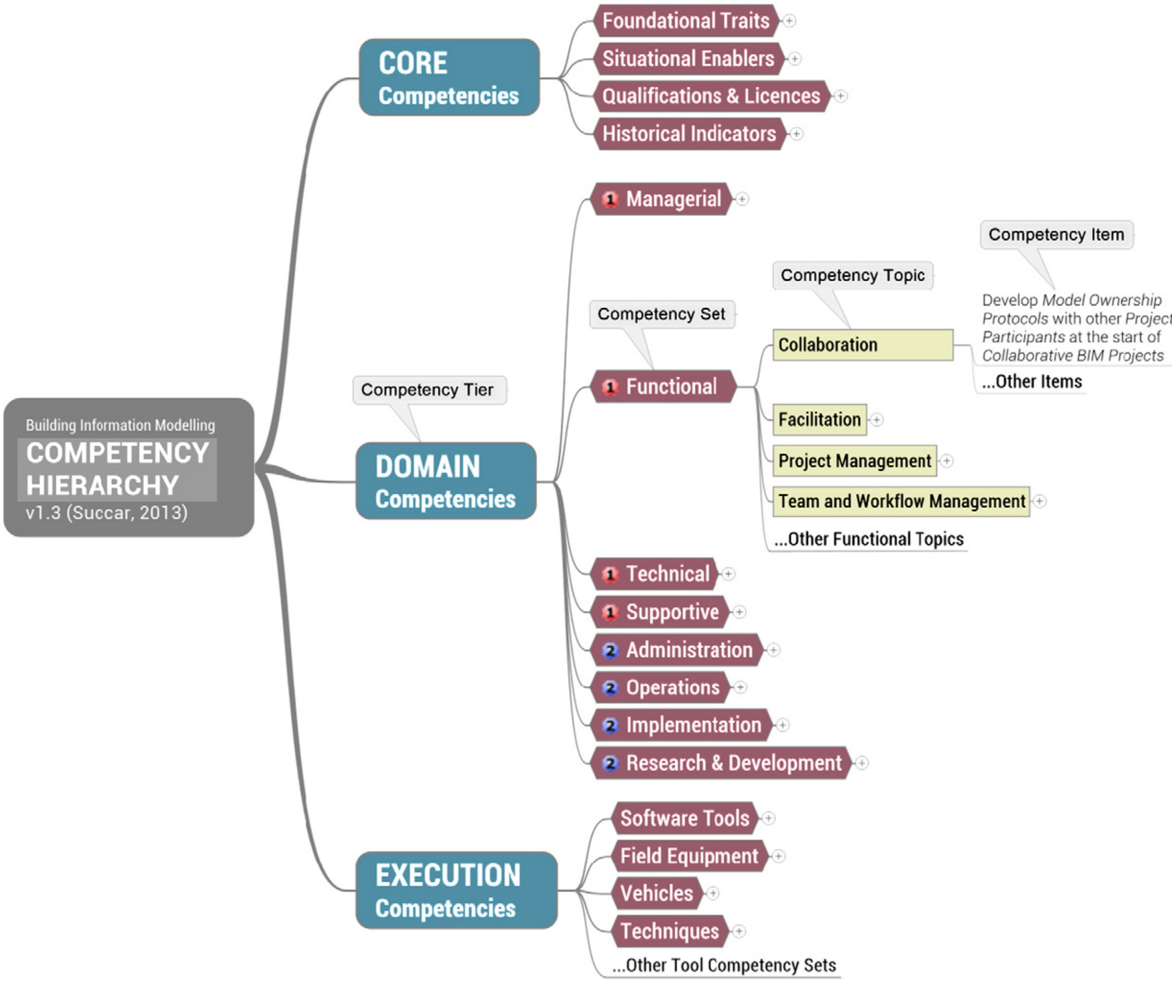

Fig. 6. BIM competency hierarchy — a multi-level taxonomy for organizing individual BIM competencies.

needs" ([53] — page 1510), individuals' core abilities form part of the organisation's core competence.

6.2. Tier 2: domain competencies

The domain competencies tier (Fig. 6) refers to the *professional abilities* of individuals, the *means* they use to perform multi-task activities and the *methods* they employ to deliver outcomes with complex requirements. There are eight competency sets within this tier: four primary sets (managerial, functional, technical and supportive) representing the main types of professional ability; and four secondary sets (administration, operation, implementation and research & development) identifying those abilities which are formed by the overlap of Primary Sets (Fig. 7):

1. *Primary competency sets* represent an individual's professional abilities distributed into the following four sets:
   a. *Managerial:* decision-making abilities which drive the selection/adoption of long-term strategies and initiatives. Managerial competencies include leadership, strategic planning and organisational management (e.g. '*the ability* to understand the Business Benefits and Business Risks of model-based workflows' is a *competency item* within the strategic planning *competency topic*, within the managerial *competency set*);
   b. *Functional:* the non-technical, overall abilities required to initiate, manage and deliver projects. Functional competencies include collaboration, facilitation, project management… (e.g. *the ability* to facilitate a multi-disciplinary BIM meeting);
   c. *Technical:* the individual abilities required to generate project deliverables across disciplines and specialities. Technical competencies include modelling, drafting, model management… (e.g. *the ability* to use BIM Software Tools to generate accurate, error-free models); and
   d. *Supportive:* these competencies are the abilities required to maintain information and communication technology (ICT) systems. They include ICT support, hardware maintenance, software troubleshooting… (e.g. *the ability* to assist others to troubleshoot basic software and hardware issues).
2. *Secondary competency sets* represents an individual's ancillary professional abilities. They include the following four sets:
   a. *Administration:* the activities required to fulfil and maintain organisational objectives. Administration competencies include tendering and procurement, contract management and human resource management (e.g. *the ability* to establish the necessary metrics to measure the financial performance of BIM projects);
   b. *Operation*: the practices and efforts required to deliver a project or part/aspect of a project. Operational competencies include designing, analysing, simulating and estimating (e.g. *the ability* to use models to generate bill(s) of quantities);
   c. *Implementation:* the activities required to introduce transformative concepts and tools (revolutionary or evolutionary) into an organisation. Implementation competencies include component

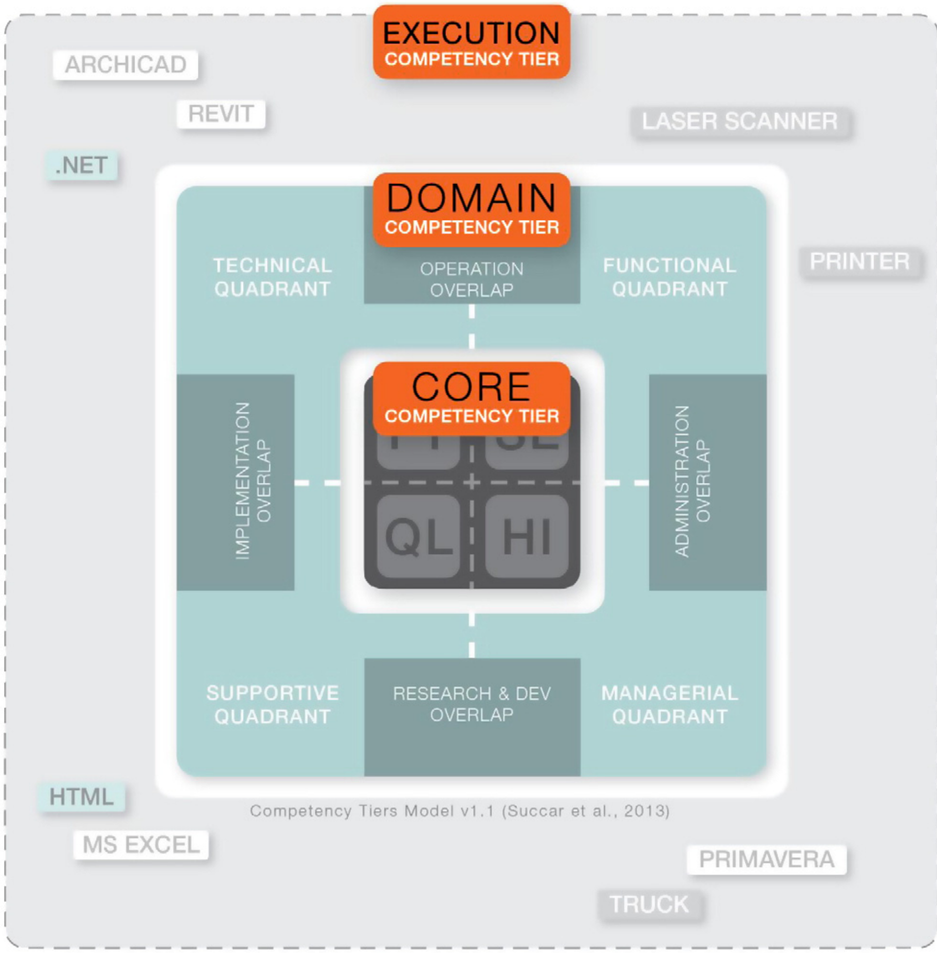

Fig. 7. Competencies tiers model.

development, library management and standardisation (e.g. *the ability* to develop protocols specific to generating and maintaining a Model Component Library); and

d. *Research and Development:* the activities required to evaluate existing processes, investigate new solutions and facilitate their adoption within the organisation or by the larger industry. Research and development competencies include change management, knowledge engineering, research and coaching (e.g. *the ability* to monitor, select and recommend technological solutions to enhance organisational workflows and deliverables).

6.3. Tier 3: execution competencies

The execution competencies tier (Fig. 6) represents an individual's ability to use specific *tools* and *techniques* to conduct an activity or deliver a measureable outcome. The ability to use a software tool (e.g. a 3D model authoring tool), drive a vehicle (e.g. a 30 tonne tipper truck) or operate specialized field equipment (e.g. a laser scanner) are examples of execution tier competencies. Also, the ability to employ specialized *techniques* (e.g. programming, drawing and plastering) is also classified under the Execution Competency Tier.

Competencies organized by tiers, sets and topics complement each other. That is, for an individual to deliver an activity, a mixture of competencies from across all three tiers is typically required. For example, for a structural engineer to efficiently generate and exchange a data-rich 3D model with an architect, she/he will require *core* engineering qualifications, BIM *domain* expertise (knowledge of collaboration requirements and data exchange protocols) and *execution* abilities (ability to use modelling and data exchange tools). Table 3 further clarifies how competencies complement each other from across different tiers, sets and topics:

In addition to the BIM competency hierarchy – the main skeleton around which BIM competencies are organized – auxiliary classifications criteria (competency labels) may concurrently apply. For example, competencies may be as labelled as *generic* or *specialized*. Generic BIM competencies are equally valid across all disciplines, specialties and roles; while *specialized* competencies are valid only within a subset of disciplines, specialties and roles:

- An *architect* (Discipline A) developing a 3D spatial model for a hospital building would require a *different set* of competencies from those required by an *engineer* (Discipline B) performing thermal analysis of the hospital's zones. However both individuals would need to *know how* to exchange data and communicate their respective requirements.
- The daily activities required from *a junior draftsperson* (Role A) engaged in generating 3D models or documents are not the same as those required by a *team manager* (Role B) responsible for coordinating the efforts of many individuals. However, both individuals would need to *know what* documentation and delivery standards to apply.

Irrespective of the labels used, classification is the meaningful clustering of experience [50]. Organizing BIM competencies in this manner allows for the meaningful aggregation of BIM knowledge, skill and experience into a structured inventory to be used for industry-wide performance assessment and improvement.

Table 3
Competencies complement each other from across different tiers, sets and topics.

Core competencies	Domain competencies	Execution competencies
Competency topic (Competency set)	Competency topic (Competency set)	Competency item (Competency set > competency topic)
Creativity (foundational traits)	Design conceptualisation (operations)	ArchiCAD (Software tools > model authoring)
Diploma e.g. dip in project management (Qualification and licences)	Project management (Functional)	Primavera (Software tools > project management)
Driving license (Qualification and licences)	[No complementary competency]	Car (Vehicles > transportation)
Curiosity (Foundational traits)	Research and analysis (Research and development)	Nvivo (Software tools > data analysis)
Time management (Foundational traits)	[No complementary competency]	Getting things done (GTD) (Techniques > organisation)
Market experience (Situational enablers)	[No complementary competency]	[No complementary competency]
Strategic mindset (Foundational traits)	Strategic planning (Managerial)	[No complementary competency]
[No complementary competency]	Web development (Supportive)	HTML (Techniques > programming)
Previous positions e.g. in management (Historical indicators)	General management (Managerial)	BPMN (Techniques > representation)

7. Generic BIM competencies — a seed inventory

There are arguably hundreds of *generic* BIM competencies common across disciplines, specialties and roles. There are also, depending on the level of detail used to define competencies, thousands of *specialized* BIM competencies reflecting the unique requirements of each discipline, specialty and role (e.g. structural engineers, ducting sub-contractors and site managers respectively). Table 4 introduces a seed inventory of *generic* BIM domain competencies and provides sample competency items for each of its eight competency sets:

The seed competency inventory (Table 4) includes sample competency items formulated using a standardized *sentence structure* and employing standardized *BIM terminology* (shown underlined). These BIM terms are part of a *BIM dictionary*, a discrete inventory developed to clarify the meaning of terms used within competency items. The dictionary eliminates conflicting definitions; identifies synonyms or term variations across markets; and allows competency items to be succinctly formulated. Most importantly, the BIM dictionary acts as a *web of meaning* [18] connecting terms to each other; to learning material; to knowledge bases; and to competency items which use them. Table 5 provides

Table 4
Seed BIM domain competency inventory.

Competency set	Competency topic (Partial)	Individual BIM Competency Item (Sample items at low-detail definition; expressed as activities)
Managerial	Leadership	Generate an overall mission statement covering BIM Implementation within an organisation
	Strategic planning	Define the strategic objectives to be achieved from implementing BIM software tools and model-based workflows
	Organisational management	Identify changes to organisational processes as necessary to benefit from model-based workflows
Administration	Administration, policies and procedures	Organize initiatives to encourage staff to adopt BIM software tools and workflows within the organisation
	finance, accounting and budgeting	Establish the necessary *metrics* to measure the financial performance of BIM projects
	Human resource management	Identify the responsibilities of a BIM manager, a model manager and similar BIM roles
Functional	Collaboration	Develop model ownership protocols with other project participants at/before the start of collaborative BIM projects
	Facilitation	Act as the project team's BIM facilitator during the delivery of collaborative BIM projects
	Team and workflow management	Use a content management system or a document management *system* to manage information storage and sharing
Operation	Designing and conceptualizing	Use a BIM software tool to generate a rough representation of a space through basic geometry and identify spatial relationships
	Analysing and simulating	Use specialized software tools to generate a thermal study from a data rich 3D model
	Quantifying and estimating	Prepare a BIModel for the purpose of linking it to a construction schedule
Technical	Modelling and drafting	Generate BIModels using a pre-defined set of standards and guidelines
	Documentation and detailing	Generate *2D Drawings* of an accuracy suitable for construction documentation and submittal for *Tender/Bid*
	Model management	Maintain a *BIModel* according to modelling standards set by the organisation or project team
Implementation	Implementation fundamentals	Compare different BIM software tools and select the one most suitable for an organisation
	Component development	Generate basic model components which comply with organisation's modelling standards
	Technical training	Develop a skill register, a training log or similar to track existing and newly acquired skills
Supportive	IT support	Conduct tests to establish whether IT systems are running at required levels of performance and stability
	Software and web development	Develop tools/extensions to improve the project deliverables of off-the-shelf BIM software tools
	software-related troubleshooting	Manage the relationship between an organisation and its BIM software tool vendor/reseller
Research and development	General R&D	Generate a BIM-specific R&D plan for an organisation
	Teaching and coaching	Develop a well-defined approach to identify change resistance or change saturation during the BIM implementation process
	Industry engagement and knowledge sharing	Develop non-technical educational material to assist staff in understanding the business and process requirements of BIM

Table 5
Sample BIM dictionary terms and their BIM-specific definitions.

Terms (similar terms)	BIM specific definition	Further reading
Algorithmic model	A model generated using algorithmic functions manipulated by the end-user to explore design form or function. A typical use of Algorithmic Models is form-finding, where computational methods are used to drive shape generation, what-if scenarios and structural optimisation. While Algorithmic Models are a type of Parametric Models, they are not necessarily object-based and may only be loosely labelled as BIModels (e.g. Bentley's Generative Components is a software specialized in generating Algorithmic Models which can then be linked to BIModels).	[47]
Code checking and validation (Code validation; constraint checking; rule-based checking)	A process using a Specialized Software Tool to check for the compliance of model parameters against design, performance and/or safety codes.	[17]
Project complexity	Project complexity is measurement of how difficult a project is to design and construct. Project complexity is identified through a collection of variables which include site constraints, shape of structure, scale, scope, skill availability, cost constraints, legal framework, logistics, etc.	[12]

three sample BIM terms – out of hundreds needed[7] – and their BIM-specific definitions:

These standardized terms clarify BIM concepts, deliverables and their requirements across competency items, topics, sets and tiers. The semantic connectivity achieved by the BIM dictionary provides consistency and allows each competency item to be used in a variety of goal-driven and complementary ways.

8. BIM competency use — a sample model

There are several ways to benefit from the BIM domain competency inventory (Table 4) and its expansive list of structured competency items. The Triple A Competency Model (Fig. 8) is a *knowledge engine* [5,21] which uses structured BIM competency items to perform three complementary actions -competency acquisition, competency application and competency assessment. These actions are described below.

8.1. Competency acquisition

Competency acquisition is the *action referring to the process of learning* through competency items. This is achieved by purposefully collating BIM competency items into *BIM Learning Modules* to be used in professional development, vocational training and tertiary education. Using the many competency classifications and labels introduced earlier, learning modules – also referred to as *learning objects* [6] – can be formulated at an appropriate level of detail and fulfils the educational requirements of a target audience — be it an undergraduate student, a tradesperson, or a construction manager. Table 6 exemplifies how BIM competency sets and topics are used to generate sample BIM Learning Modules:

Competency items and topics can thus be used – when purposefully collated into BIM learning modules – for acquisition and improvement of individual knowledge and skill. According to Voorhees ([88], page 9), a "single competency can be used in many different ways […] The challenge is to determine which competencies can be bundled together to provide different types of learners with the optimal combination of skills and knowledge needed to perform a specific task".

8.2. Competency application

Competency application is *the action referring to the process of using* competency items to conduct an activity or deliver a measurable outcome. There are several approaches in *applying* structured BIM competencies - competency items can be used to:

1. Populate task lists for initiating projects and processes (e.g. a step-by-step guide for importing geometry drawn outside a Gehry Technologies Digital Project) or quality-checking project deliverables (e.g. a check list for auditing a model's quality);
2. Generate standardized mind maps, workflow diagrams and similar charts to clarify BIM implementation activities, data exchange and collaboration processes; and
3. Establish project requirements for the purposes of procuring services — e.g. through using competency items to populate a request for qualification or request for proposal.

Fig. 9 below illustrates how individual BIM competencies can be used to generate BIM workflows through a structured graphical language – shown here using Business Process Modelling Notation [65].

The partial workflow (Fig. 9) uses BIM competency items from across several Competency Sets to clarify a specific process — how to initiate a collaborative BIM project. The BPMN concepts are represented at *low detail* and can be expanded into several sub-processes populated with competency items at higher levels of detail.

8.3. Competency assessment

Competency assessment is an action *referring to the process of measuring* the abilities of individuals within both professional and academic settings. From an organisational perspective, individual competencies – knowledge, skill and personal traits – are the "most important resources of a company for solving knowledge-intensive tasks such as decision-making, strategic planning, or creative design" ([72], page 506). These individual competencies – of employees for example – may not be always explicit. Through assessment, the availability and extent of an employee's competency can be made explicit, rendering it "easier to find out what people know or to direct people to others who can be of help. This sharing of information improves the organisational productivity as well as the individual performance" ([72], page 507).

Fig. 10 below demonstrates how competency items can be used to measure Individual BIM competencies through a dedicated online assessment tool.[8] In this example, individuals have been asked to assess their own abilities using the 5-level BIM competency index.

Competency assessment not only facilitates HR management processes within organisational settings (e.g. HR selection, planning, and succession planning), but can also "help to predict project management performance against a range of key performance criteria" ([19], page 2). Structured competencies enable the generation of an assessment framework for competency-based learning that measures what learners know or can accomplish through precise descriptions [88].

[7] The BIM Dictionary has been implemented as a free online tool http://www.BIMexcellence.net/dictionary. (Developed by ChangeAgents AEC and released under a Creative Commons 3.0 license. The BIM Dictionary currently includes more than 330 interlinked BIM terms and their research-based definitions.

[8] The image shown is from BIMexcellence.net, individual discovery (Beta 1). Competency items shown are from the domain tier > functional set > collaboration topic.

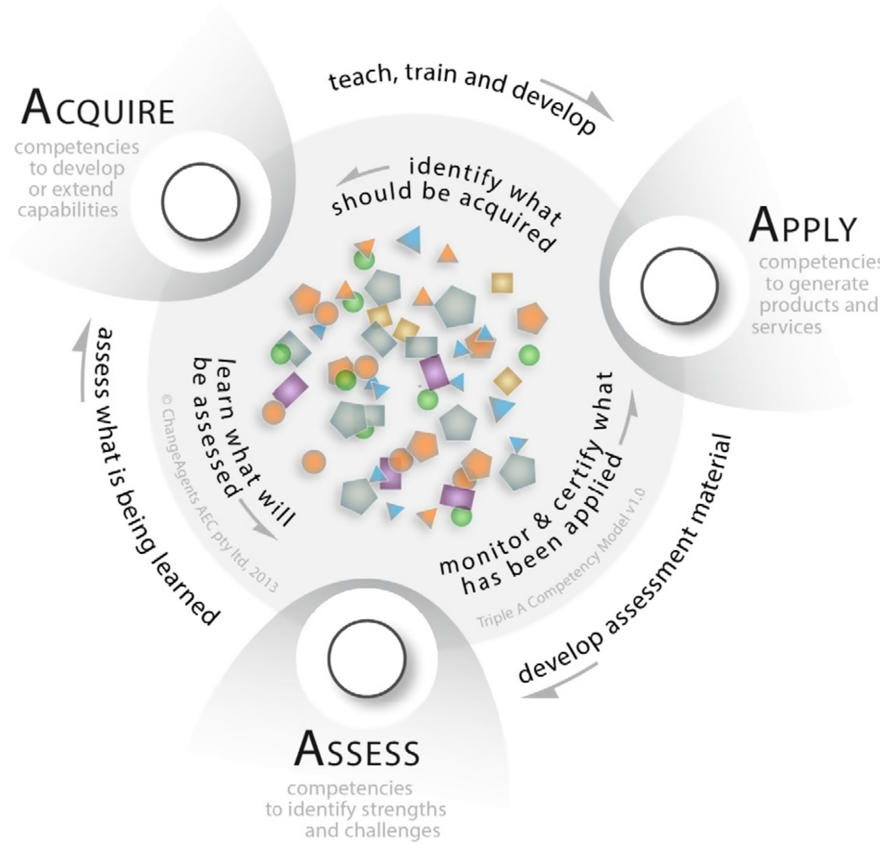

Fig. 8. The triple A competency model — coloured shapes denote discrete competency items.

9. Three actions — multiple uses

The three actions introduced in the Triple A Competency Model (Fig. 7) have numerous applications when used in conjunction with structured BIM competencies. Depending on the competency syntax (i.e. *how* a competency item is worded) and its intended use, every item derived from the competency inventory (Table 4) can concurrently enable learning, assessment and practical application. Separating the syntax from the competency item – and thus not identifying competency items as *specific behavioural tasks* –

Table 6
BIM learning modules — formulated using BIM competency sets and topics.

Course, lecture or lesson	Learning modules (Competency tier > set > topic)	Discipline and sector (Target audience)	Delivery level (Delivery method)	Prerequisites
BIM basics	Introduction to building information modelling concepts (Domain > functional > functional basics)	33 (code 33 denote all disciplines and roles, please refer to legend)	Level 1 (Video)	N/A
	Autodesk revit — fundamentals (Execution > software tools > model authoring)		Level 1 (Lab)	
BIM legal	Contractual implications of using 3D models as a primary source of design information (Domain > administration > contract management)	33-21 (BIM managers, senior technical staff — design discipline)	Level 2 (Workshop)	All contract management topics at level 1
BIM project facilitation	Developing a BIM management plan (Domain > functional > facilitation)	33 (project managers, clients, facility managers)	Level 2 (Workshop)	All functional set at level 1 + understanding data exchange protocols at level 2
	Understanding data exchange protocols (Domain > technical > data and networks)		Level 2 (Presentation)	
	Understanding model progression specifications (Domain > technical > model management)		Level 2 (Workshop)	All of technical set at level 1
	Document management — general (Execution > web tools > document management)		Level 1 (Presentation)	N/A
Model management for collaborative projects	Understanding data exchange protocols (Domain > technical > data and networks)	33 (BIM managers, senior technical staff — all disciplines)	Level 2 (Online presentation)	All data and networks topics at level 1
	Model auditing for model managers (Domain > technical > model management)		Level 3 (Lab)	All model management topics at levels 1 and 2

Legend:
Discipline and sector are based on OmniClass Table 33. OmniClass is an Open Standard developed by the Construction Specifications Institute (CSI) — http://www.omniclasss.org/.
Delivery level is a classification applied to each BIM topic to indicate prerequisite levels of knowledge, skill, and experience (e.g. Delivery Level 1 topics focus on 'BIM awareness' and have no prerequisites).
Delivery method identifies the recommended format(s) for delivering a BIM topic to a target audience.

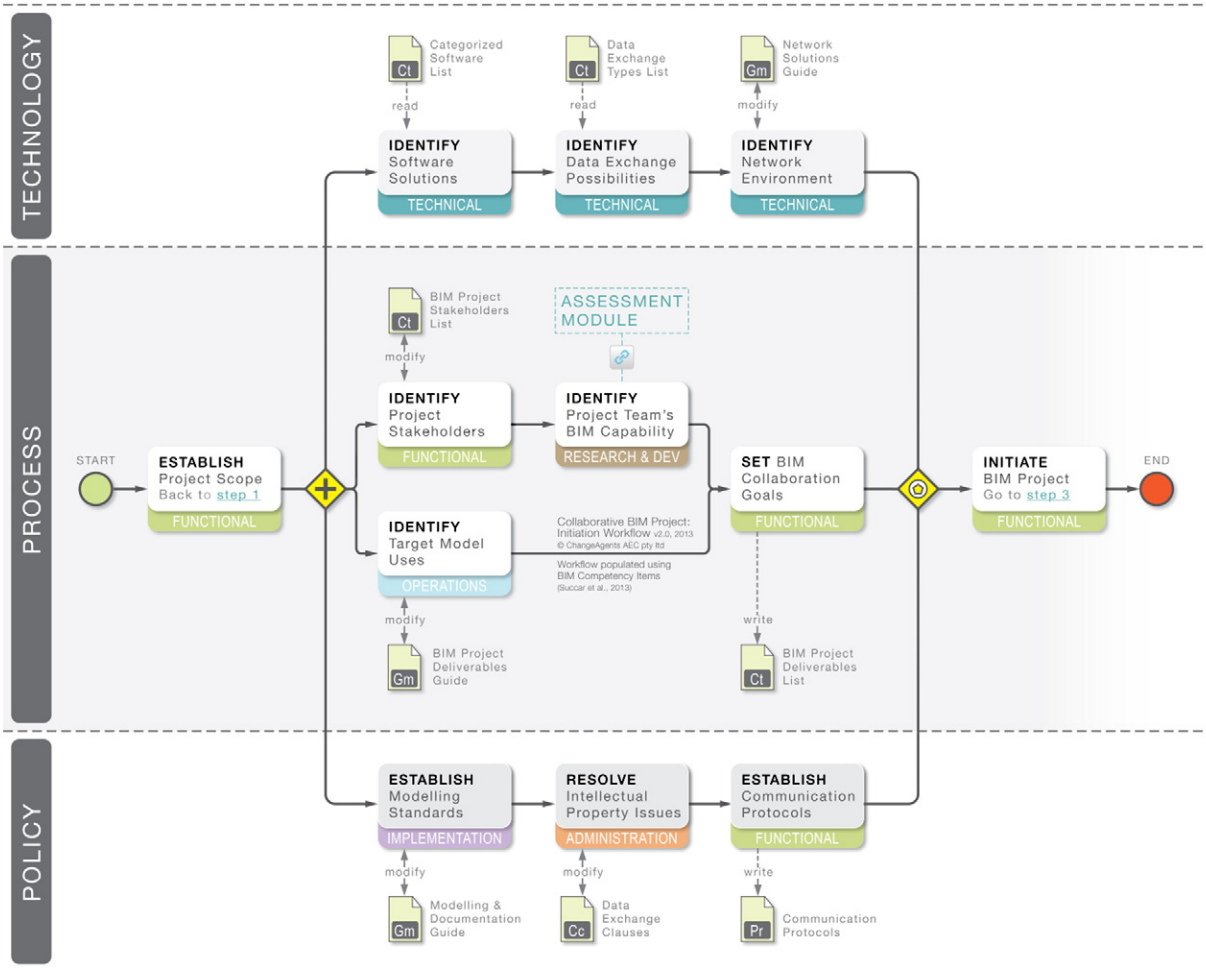

Fig. 9. Collaborative BIM project initiation workflow — v2.0.

provides the inventory with flexibility and adaptability ([32] page 783). Table 7 demonstrates how a sample competency item – *prepare a 3D model for the purpose of linking it to a construction schedule* – is *acted upon* to deliver multiple uses across several units of analysis.

Table 7 depicts how a sample competency item can be used for competency assessment, application and acquisition. Modifying the competency syntax to establish frequency, detail, evidence or priority would further qualify and extend the use and reuse of every item within the BIM competency inventory.

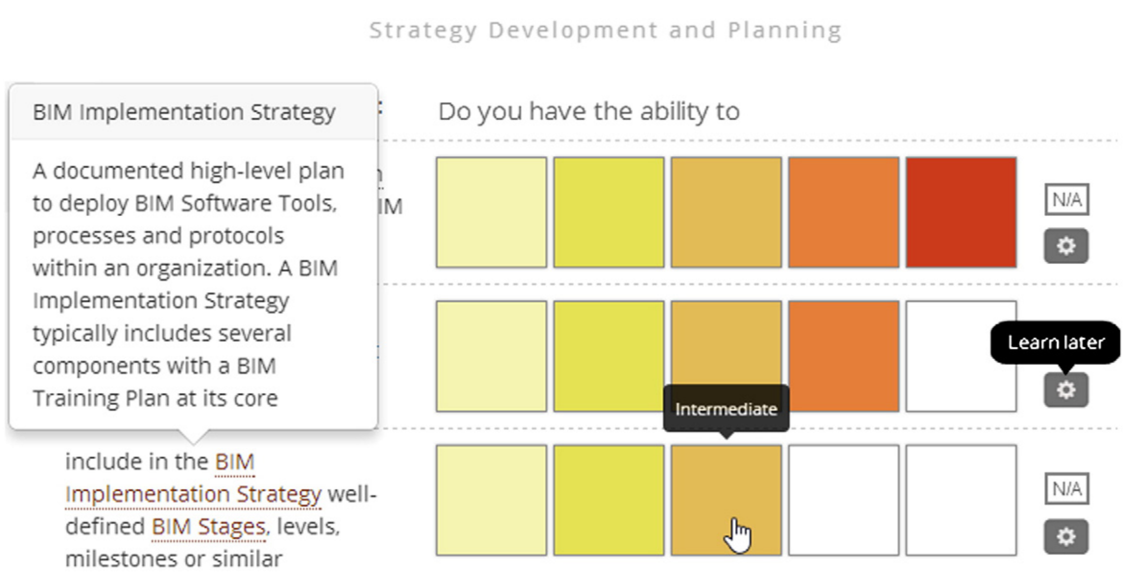

Fig. 10. Individual BIM competency assessment — *as applied in BIMexcellecne.net (beta 1)*.

Table 7
Sample competency item across actions, units of analysis, applications and measurements.

Action (More info)	Competency [syntax] "Competency item"	Unit of analysis (More info)	Intended use	Applicable metrics
Assess (The primary action for measuring the availability/level of competencies)	[Do you] [have the ability to] "*prepare a 3D model for the purpose of linking it to a Construction Schedule*"	Individual	Competency assessment	BIM**CI**
	[Do you] [have the ability to] [teach students to] "…"	Individual (educator)	Competency assessment	BIM**CI** or BLOM
	[Does your organisation] [have] [protocols] [explaining how to] "…"	Organisation (company)	Capability assessment	BIM**CS** and BIMMI
	[Should universities] [teach] [students] [the ability to] "…"	Organisation (institution)	Educational planning	BIM**CI** or BLOM
	[Does the curriculum] [provide for] [students] [to] [learn how to] "…"	Organisation (institution)	Curriculum assessment	
	[Does this] <<team>> [have] [the ability to] "…"	Team (work team)	Competency assessment	∑ BIMCI
		Team (project team)	Competency assessment	
		Team (org team)	Capability assessment	BI**MCS** and BIMMI
	[Does this] [project] [include] [a requirement to] "…"	Project	Requirements assessment	BIMCI
Acquire (The primary action for learning competencies)	[At the end of the] [course], [students] [of] <<course name>> [would] [have learned how to] "*prepare a 3D model for the purpose of linking it to a Construction Schedule*"	Individual (student)	Education	BIM**CI** or BLOM
	[You] [will need to] [develop the necessary skills to] "…"	Individual	Development	BIMCI
	[All] <<role group>> s [will receive training in] [how to] "…"	Group (individuals with the same role)	Training	∑ BIMCI
Apply (The primary action for implementing and managing competencies)	[Use] <<software tool>> [to] "*prepare a 3D model for the purpose of linking it to a Construction Schedule*"	Individual	Project/org requirement	N/A
	[Work team] <<team code>> [is the responsible party to] "…"	Team	Quality checking	
	…[After completing step] <<step code>> [your] [organisation] [will need to] "…"	Organisation	Project/org requirement	

Legend:

[brackets]	Competency syntax [shown in brackets] is derived from the conceptual BIM Ontology [80].
Italics	Sample competency item is shown in "*italics*" and is to be repeated at each row after the [syntax].
<<chevrons>>	Text in <<chevrons>> indicates variable to be replaced.
BIMCI	BIM competency index (Fig. 2).
∑ BIMCI	Aggregate BIMCI; an arithmetic sum of the competencies of several individuals.
BIMCS	BIM capability stages (Fig. 3).
BIMMI	BIM Maturity Index (Fig. 4).
BLOM	Bloom's taxonomy [49].

10. Concluding remarks

Numerous benefits accrue from identifying, classifying and aggregating generic BIM competencies - devoid of syntax, weight, specialisation, action and delivery method – into a structured inventory. Acting as a *common BIM competency language*, generic competencies can then be customized to *enable or support* the development of BIM-focused *profile and competency management systems* [26,16]; *e-portfolio* and *learning management* systems [79,69,44,56]; continuous *education, training* and *professional development* [83]; and a research-based *BIM-competency certification and accreditation regime* [1,15]. In essence, an integrated approach to competency identification, classification and aggregation will enable the delivery of a comprehensive yet flexible competency-based system for assessment, learning and performance-improvement across both industry and academia:

Across industry, the availability of a structured set of BIM competencies would assist organisations and project partners to:

- Identify BIM goals and objectives through competencies *expressed as abilities*. For example, an organisation can identify the 'ability to deliver BIM-FM services' as a strategic objective to guide its software implementation and recruitment strategy;
- Measure the competency/capability of individuals, organisations and teams using a common reference set. With standardised competency definitions – *expressed as abilities* – individuals, groups, teams, and organisational units can be compared and aligned;
- Define and meet project requirements through standardised competencies *expressed as abilities/requirements*. For example, project activities can be listed and analysed to identify required competencies and to estimate project cost/duration;
- Facilitate organisational and project workflows through competencies – *expressed as activities/tasks*. Task lists can be used to optimise project delivery across an organisation and to facilitate quality checking at different phases of each project's lifecycle;
- Identify pre-qualification criteria through competencies – *expressed as outcomes/deliverables* – within procurement and tender/bid documents; and
- Develop training and continuing professional development (CPD) modules – *expressed as outcomes* – within organisations and industry associations.

Within academia, the availability of a structured set of BIM competencies would assist vocational and tertiary level institutions to:

- Conduct investigations based on a standardised set of BIM competencies – *expressed as abilities*. This reference set could be used to survey industry, establish its competency requirements, and then compare these requirements to current educational deliverables;

- Identify educational goals related to BIM education[9] through competencies *expressed as learning outcomes*. These goals can inform[10] curricula design and facilitate the development of BIM learning modules;
- Measure the competency of students and lecturers using a common reference set. With standardised competency definitions - *expressed as abilities* – both learner and learning provider can be uniformly assessed against competency topics and sets.

These are the main benefits expected from developing an industry-wide BIM competency inventory. Other benefits are subject to further development of semantic tools which best utilize and extend the use of structured BIM competencies.

11. Future work

This paper has explored individual competencies, the fundamental building blocks of organisational capability. Expanding on previous research, several formative classifications have been introduced and used to develop an integrated definition of *Individual BIM Competency*. This integrated definition acted as a conceptual filter to isolate target competencies which were then classified through a specialized taxonomy and used to populate a seed inventory of generic BIM competencies. A knowledge engine was then introduced to demonstrate how each structured competency item could be used for the complementary purposes of competency acquisition, application and learning.

This research serves as a foundation for future investigations into integrated competency improvement within the DCO industry. Further research is needed to develop a BIM-specific *competence ontology* [22,36] and to match the BIM *competency inventory* with widely adopted definitions and metadata standards [41,39]. Additional efforts are also needed to expand the *competency identification, classification, aggregation* and *multiuse* workflow (Fig. 5) into a framework that supports competency-based learning, assessment and performance improvement. Three main avenues are identified and will be actively pursued to extend this research: first, engaging with industry associations to *gradually* identify, classify and aggregate specialized BIM competencies from across disciplines and specialties; second, developing seed competency-based learning modules which satisfy the BIM educational requirements of sample organisations, industry associations and educational institutions; and third, developing a semantic web-based solution[11] that hosts the *knowledge engine* (Fig. 8) and delivers a set of *integrated* BIM assessment tools, learning objects and workflow modules.

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[9] As noted by Macdonald ([55], page 223), various studies indicate that tertiary education is lagging behind the construction industry in moving towards collaborative, BIM-enabled working practices.

[10] The seed BIM competency inventory has played a role in informing a BIM Education initiative [84] — an industry effort conducted by the Australian Institute of Architects and Consult Australia in 2012.

[11] This is currently being developed through BIM Excellence, a commercially-supported not-for-profit initiative partially based on this research.

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