I. Introduction

BIM Excellence (BIMe) is a unique *research-based* approach to digital innovation in the construction industry. It provides an integrated methodology and a modular language for performance assessment, learning and process optimisation. The **BIMe Initiative** is *not-for-profit effort* guided by a set of **Principles**[1] undertaken by volunteer researchers from both industry and academia. The BIMe Initiative is supported by in-kind contributions, commercial services, and institutional/corporate sponsorship.

> *T* This document must be read in conjunction with ***101in BIMe Initiative Explainer***, ***102in BIMe Initiative Knowledge Structures***, ***103in BIMe Initiative Projects***, and ***104in BIMe Initiative Network*** (refer to list of downloadable resources). The BIM Excellence approach and the BIMe Initiative are based on the published research of *Dr. Bilal Succar* and a growing cohort of esteemed international collaborators.

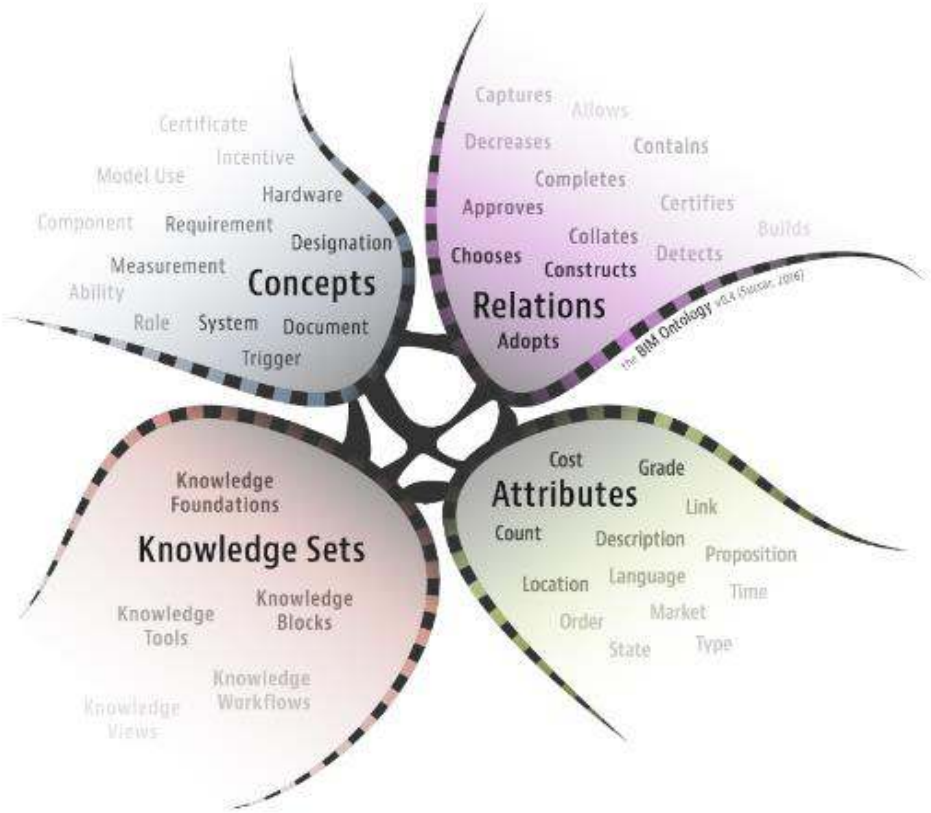

Figure 1. The BIM Ontology - Visual Knowledge Model

[1] BIMe Initiative Principles (BIMe Principles, or Principles for short) includes both General Principles and the Excellence Manifesto.

II. Background Research

The Conceptual BIM Ontology is an informal, semi-structured, conceptual domain ontology used for knowledge acquisition and communication between people. It is intended to represent knowledge interactions (push/pull) between BIM players, their deliverables and requirements (Figure 2) as described within Papers A1 and A2 (Succar, Sher, & Aranda-Mena, 2007) (Succar, 2009) and facilitate the validation of conceptual models (Shanks, Tansley, & Weber, 2003).

> *"An ontology defines the basic terms and relations comprising the vocabulary of a topic area as well as the rules for combining terms and relations between terms [13]. An ontology may have very high-level terms or be domain specific [19]."* (Sugumaran & Storey, 2002, p. 253).

The Conceptual BIM Ontology includes BIM-specific concepts, their relations and attributes which facilitate analysis of domain knowledge (Noy & McGuinness, 2001), enable the construction of a domain framework (Studer, Benjamins, & Fensel, 1998), and support knowledge acquisition and communication (Milton, 2007a, 2007b) (Cottam, 1999) (Studer et al., 1998). Figure 2 below illustrates how ontological objects underlie the BIM Framework.

The *concept map* (Figure 2 - right) is a visual representation of the ontological relationship between the three concepts (BIM Fields, BIM Stages, and BIM Lenses); while the *visual knowledge model* (Figure 2 - left) abstracts these relationships into the *Tri-axial Model*, a simplified graphical representation to facilitate communication. As discussed in Papers A1 and A2, this combination of visual modelling, driven by explicit ontological relations, renders the BIM Framework and its many conceptual constructs more accessible for analysis, modification and extension.

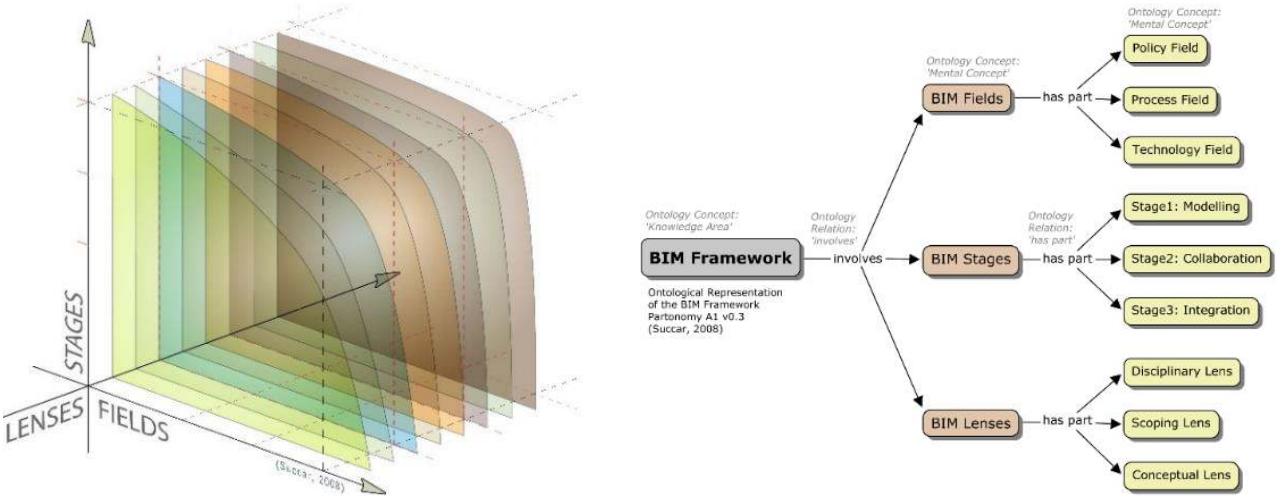

Figure 2. Knowledge model (left) + concept map representing underlying ontological structure (right)

Also, as depicted in the Conceptual Hierarchy (Figure 3), ontological relations enable a 'conceptual mesh' linking different types of *conceptual constructs*: frameworks, models, taxonomies, classifications and specialised dictionary terms.

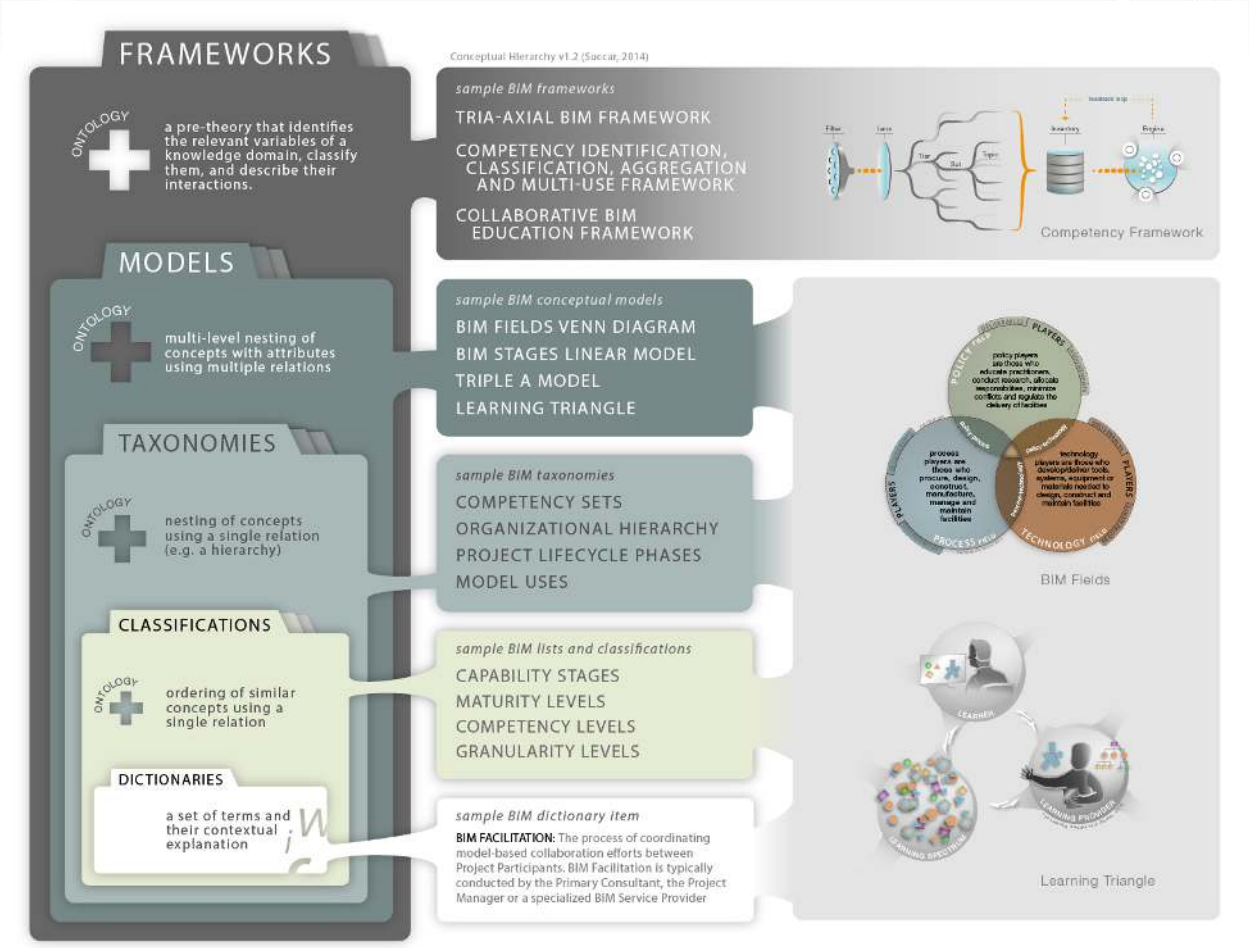

Figure 3. Conceptual Hierarchy - glued by the Conceptual BIM Ontology

A. Generating the Conceptual BIM ontology

The Conceptual BIM Ontology has been generated by amending and reusing existing ontologies; a process recommended by Noy and McGuiness (2001). The reuse of an existing ontology followed Gruber's criteria for shared ontologies: clarity, coherence, extensibility, minimal encoding bias and minimum ontological commitment (Gruber, 1995). Based on these criteria, the Conceptual BIM Ontology was first derived from the General Technological Ontology (Milton, 2007a) (Milton, 2007b) and the General Process Ontology (Cottam, 1999). While earlier iterations of the Conceptual BIM Ontology followed source definitions, newer iterations are more closely matched with the conceptual and practical requirements of the BIM domain.

B. How the Conceptual BIM Ontology will be used

The Conceptual BIM Ontology is a key part of the BIMe Initiative Knowledge Structure (refer to 102in) and is depended-upon to:

- Connect all conceptual parts within the BIM Initiative (Frameworks, Models, Taxonomies, Classifications, and Dictionaries);
- Bridge the terms within the BIM Dictionary with relevant international dictionaries and ontologies; and
- Provide the high-level structure for developing a technical/software ontology for the BIMe Initiative Integrated Information project.

C. Formalisation Efforts

The Conceptual BIM Ontology is currently being reviewed and formalised. More information about this process and its outcomes – including its release as a Web Ontology Language (OWL) - will be shared in a future version of this document.

III. Knowledge Objects

The Conceptual BIM Ontology comprises of **four high-level knowledge objects**: concepts, attributes, relations, and knowledge Sets (Table 1):

Num	Knowledge Objects	Description	Examples
1	Concepts	Mental constructs	Component; Document; Role
2	Attributes	Values and qualifiers associated with Concepts	Cost; Count; Description
3	Relations	Connections between Concepts; the effect of one Concept on another	Approves; Detects; Supplies
4	Knowledge Sets	A purposeful compilation of Concepts, their Attributes, and Relations	Knowledge Foundations; Knowledge Blocks; Knowledge Views

Table 1. Knowledge Objects Summary

Please note the following:

- The term 'knowledge' in Knowledge Objects is derived from the Data, Information, Knowledge, Understanding and Wisdom taxonomy2. As 'knowledge' refers to information parsed by a human actor, this conceptual ontology3 assumes that there is a Knowledge Subject (a human actor) combining these Knowledge Objects – through cognitive processes and motor actions – into a deliverable (an ability, an action, or an outcome);
- The Knowledge Objects are two types: higher-order and lower-order. Higher-order Knowledge Objects (Concepts, Relations, and Attributes) are granular mental constructs that – to be communicated effectively – rely on Knowledge Sets, the lower-order Knowledge Object. For example, to describe, explain or test a complex relation between multiple concepts, it may be easier to generate a hierarchy, a matrix or a visual knowledge model.

[2] Please refer to BIM ThinkSpace Episode 3: Focus on Information http://bit.ly/BIMepisode3
[3] This is the main difference between a Conceptual Ontology - intended for use by human actors - and a Software Ontology.

D. Concepts

Concepts are Mental Constructs - to be kept as few as possible:

	Concept	Sub-concepts (*description*)	Example
1	Ability	Capability; Maturity; Competency	The ability to generate a thermal study; capability to collaborate…
2	Activity	Sub-activity; Task; Sub-task	Merge models, meet client, design a stadium…
3	Certificate	License; Testament *A formal testament of capability or completion of a task*	A trainer's certificate…
4	Component	Virtual object; Sub-model; Part; Entity (ISO); Sub-entity	e.g. Revit family, GDL object…
5	Conception	Thought; Idea *A domain-specific set of ideas within a single term*	Project Lifecycle Phases, Economy of Scale…
6	Conceptual Construct	Term; Classification; Taxonomy; Conceptual model; Framework; Theory	Tri-axial framework…
7	Constraint	Limitations; Barriers	Capacity, geography, money, time…
8	Data Source	Database; Information repository	The Australian Bureaux of statistics
9	Data Use	*The intended or expected Project Deliverable from using code to connect project tasks*	Fabrication Scripting…
10	Deliverable	Outcome *Current and potential deliverables of services and digital products*	A drawing…
11	Designation	*A temporary designation of value, use or function*	Boarding area, holding space, archive volume…
12	Document	Article; Book; Publication *A digital or analogue document*	A report…
13	Document Use	*The intended or expected Project Deliverables from developing and exchanging information through Documents*	Master Plan Drawing or Minutes of Meeting…
14	Effect	*A change or a consequence of a phenomenon or action*	Solar radiation…
15	Equipment	*A single-function or multi-function digital, mechanical, or pneumatic device*	A router, pump, or air-conditioning unit…
16	Event	Occurrence *Happenings in a domain whether controlled or not*	Training session, a milestone, an accident, a data entry…
17	Example	Instance; Sample	Arup is an example of a company (an org unit…
18	Facility	*A physical structure or installation, including related site works*	A building, a bridge, or a railway station…
19	Format	*The way information is encoded (does not refer to physical characteristics)*	File formats similar to RVT, IFC or BCF…
20	Function	Purpose; Intended Use *Function applies to objects while Role applies to humans*	Measures distances, scans documents…
21	Hardware	Computers, electronic hardware, and peripherals	A laptop, tablet, desktop computer, smart phone, screen, 3D printer, 2D printer, mouse…

	Concept	Sub-concepts (*description*)	Example
22	Incentive	Enticement; Stimulus *A material or social driver of a course of action or inaction*	Profit, marketing, publicity, Intellectual property… Efficiency, hr benefits…
23	Information Use	*Intended uses and applications of project or facility information*	Model Use (e.g. model-based Clash Thermal Analysis); Document Use; Data Use
24	Knowledge Domain	Domains; Sub-domains; Disciplines; Specialities	Knowledge elicitation; Offsite Manufacturing…
25	Lesson	*A learning unit or structured course*	A lesson learned, a case study…
26	Machine	*A mechanical system with multiple moving parts*	A car, a train, an aeroplane, a robot…
27	Measurement	Measurement Unit; Metric	Degree of Certainty
28	Medium	*The physical or virtual channel used to convey information*	Radio show, illustration, twitter feed…
29	Message	Memo; Letter; Email; SMS	Email message
30	Method	Technique *Formal or informal way of conducting an activity or delivering an outcome*	Method of operation, Best Practice, an automated routine…
31	Milestone	Stage; Step; Level	A project milestone
32	Model	*A three-dimensional digital or physical representation of information*	A 3D CAD model, a 3D print…
33	Model Use	*The intended or expected Project Deliverables from generating, collaborating-on and linking Models to external database*	Clash Detection, Cost Estimation, Space Management…
34	Place	Location	Melbourne's central business district…
35	Player	Stakeholder; Actor; Practitioner	Communities of Practice; Governments; Industry Body…
36	Product	*A physical product or material*	A building, a pre-cast panel
37	Proof	Clue; Artefact	A training log providing proof of the availability of a training plan or programme…
38	Recommendation	Advice; Suggestion *A contribution of opinion (informed or uninformed)*	Modelling best practices…
39	Representation	Illustration; Gesture; Label; Sign; Signal; Symbol *An abstract depiction of a product or concept*	A road sign or a hand movement with a known meaning…
40	Requirement	Prerequisite; Condition *A mandatory characteristic*	A business or a technical demand…
41	Responsibility	*A duty towards someone or having control over something/someone*	Responsibility for delivering a well-constructed facility…
42	Result	Score; Conclusion	Fail, pass, true, false,
43	Role	Position; Occupation; Job *Also referred to as Defined Role*	Designer, supervisor, Knowledge engineer…
44	Rule	Code; Regulation	Building Code (the code itself not the document)…
45	Scenario	*The intended or desirable interactions between an actor (human or machine) with another actor to generate a predefined outcome*	A user story to be translated into a software feature, a script for a play…
46	Software Application	*A software application whether installed on a desktop, phone or in the cloud*	MS Word, Revit, Solid Works, Angry Birds App…
47	Space	*A built and identifiable enclosed area*	Room, floor…

	Concept	Sub-concepts (*description*)	Example
48	Standard	*A formal or informal set of product/service descriptions (prescriptive or performance-based) acting as a reference to be measured against*	Formal: standard door height Informal: cleaning standard, standard of care…
49	System	*A non-software routine, a set of structured activities and steps*	Filing system, eating regime…
50	System Unit	*A representation of a building system used for specifying information generation and exchange requirements within projects*	Structural system, electrical system, air conditioning system…
51	Target	Aim; Objective	End of year resolution, financial target
52	Test	Exam; Assessment *An examination or trial to establish a quality or a quantity*	Assessment campaign, blood-sugar test, driving exam…
53	Tool	*A single-function physical device (knowledge tools are covered in Knowledge Views, a higher-level ontology object)*	A screw driver, a shovel…
54	Trigger	*Special events whose occurrence initiates tasks in the domain*	Receive a sales order, change in policy…

Table 2. Concepts

E. Attributes

Attributes are values and qualifiers associated with Concepts:

	Attribute Name	Description	Examples
1	Availability	An integer or string indicating the basic existence or availability of a concept	0 or 1 (Binary); Yes or No; Available or Not Available…
2	Cost	A monetary value expressed in whole numbers, fractions, and decimals	$100…
3	Count	An expression of elemental numbers using integers	Number of staff, cars, drawings
4	Description	An explanation expressed using words, phrases, and sentences	Glossary, Descriptions…
5	Grade	A variable denoting preference or developmental achievement expressed in integers, percentages, or text	Importance (High/Low), Priority (1,2, 3), Order (first, second, third…), Degrees of Relevance, Levels of Maturity
6	Link	A hypertext connection	A hyperlink, UNC path, email address or similar…
7	Language	The language used to define a concept or a relation	Arabic, Chinese, English…
8	Location	The coordinates of an object within a physical space	Geo Tag, x/y/z…
9	Market	A defined economical boundary	European Economic Area (EEA)….
10	Order	An arrangement whether chronological or spatial – not preferential or developmental (refer to Grade)	Project Phases, Organizational Scales…
11	Proposition	A mutually exclusive distinction between clear choices	Left or Right, True, or False (or not known) ….
12	Size	The dimensions of a measurable concept	Large or small; 200cms; 2ft
13	State	A description of condition whether temporary or permanent	Final submission, published, archived, in progress…
14	Time	An expression of chronology expressed in minutes, second, days, etc…	10 weeks…
15	Type	A differentiation of genus	Gender (male/Female)…

Table 3. Attributes

F. Relations

Relations are connections between Concepts:

A			
Abort	Adopt	Aggregate	Affect
Allow	Allow for	Analyse	Append
Approve	Arrange	Assemble	Assess
Analyse	Archive	Audit	Authorise
B			
Build	Buy		
C			
Capture	Cause	Certify	Check
Choose	Classify	Complete	Collaborate with
Collate	Collect	Commission	Communicate with
Compare	Conduct	Confirm	Construct
Consult	Contact	Contain	Continue
Control	Coordinate		
D			
Decommission	Decrease	Delete	Delimit
Deliver	Demolish	Demonstrate	Deselect
Design	Detect	Determine	Describe
Develop	Digitise	Discard	Discover
Dispose	Divide	Discuss with	Document
Draw			
E			
Edit	Educate	Empower	Encourage
Enforce	Engage with	Establish	Estimate
Exchange	Explode	Extend	Extract
Evaluate			
F			
Fabricate	Facilitate	Federate	Follow
Forecast	Function as		
G			
Gather	Generate	Guide	
H			
Harmonise	Has part	Has resource	
I			
Identify	Ignore	Implement	
Improve	Incentivise	Increase	Inform
Initiate	Innovate	Integrate	Interchange
Interview	Invent	Involve	

J			
Join			
K			
Keep Current	Know		
L			
Lead	Link to	Locate	
M			
Maintain	Make aware	Make	Maintain
Manage	Maximise	Measure	Merge
Minimise	Model	Monitor	
N			
Notify			
O			
Observe	Operate	Own	
P			
Participate in	Perform	Plan	Populate
Prepare	Prescribe	Print	Prioritise
Procure	Produce	Prove	Provide
Provide Access	Provide for	Pull	Push
Q			
Qualify	Quantify	Question	
R			
Receive	Recommend	Regulate	Reject
Replace	Represent	Request	Require
Retrieve	Revise	Review	Run
S			
Sample	Select	Share	Simulate
Start	Stop	Store	Supply
Survey	Synchronise		
T			
Test	Track	Train	Transfer
Transform	Transmit		
U			
Understand	Update	Use	
V			
Validate	Verify	View	Visualise
W			
Warn	Write		

G. Knowledge Sets

Knowledge Sets are a purposeful compilation of Concepts, their Attributes, and Relations:

	Name	Description	Example
1	Knowledge Foundations	A *structured view* of concepts and their relations. Knowledge Foundations include dictionaries, classifications, taxonomies, models, frameworks, and theories.	The Conceptual BIM Ontology, the BIM Framework, Granularity Levels, Organizational Scales, etc.
2	Knowledge Blocks	A self-contained knowledge item used to build larger knowledge structures	A competency item, dictionary item, model use, etc.
3	Knowledge Tools	An *interactive view* of concepts and their relations intended to assess, assist, and educate its users. A tool has modifiable variables leading to varied outputs based on inputs	A calculator, an online tool, a cad software, etc.
4	Knowledge Workflows	A *repeatable* set of activities conducted as part of a larger process to deliver a measurable outcome	An assessment methodology, a knowledge capture technique, a construction method, a verification routine, etc.
5	Knowledge Views	A representation of multiple concepts and their relations - irrespective of *format* (text, images, or graphs) or *medium* (physical/virtual digital or analogue)	A training manual, journal article, CAD drawing, poster, web page, video, concept map, repertory grid, process map, concept map, flowchart, Gantt chart, etc.

Table 4. Knowledge Sets

Please note the following:

- → Knowledge Sets are thus *higher order* Knowledge Objects composed of the other three *lower order* concepts, relations, and attributes.
- → Knowledge Sets provide the structure for all projects and deliverables of the not-for-profit BIMe Initiative – More info: http://bimexcellence.org/principles/knowledge-structure/

IV. Change Log

V.	Date	Applies to	Description
1.0	18 Oct '07	All	Initial version prepared for Updated Research Proposal
1.1	8 Mar '08	Concepts	Organizational Group becomes Organizational Unit – Description broadened to include Markets, Industries, Disciplines and their sub-parts
			Modify description of Recommendation (added intent to generate action)
			Added Deliverables
			Modified examples under Incentives (broadened)
			Added Human Resources
			Modified examples of Information Resources (added graphical and non-graphical databases)
			Modified Places to Locations (broader meaning – reverted to GTO's original term)
			Modified description of Agents (included Organizational Champions and renamed managerial consultant to Industrial Consultant)
			Modified description of Social Phenomena (added innovation & championship)
			Modified Software Tools to Software Applications
1.2	26 Jul '08	Concepts	Modified description of Social Phenomena (modified respectability, trust worthiness, risk-tolerance, cultural values and added leadership)
		Attributes	Modified description of Number (added monetary value)
1.2	6 Dec '08		**Published (online) as Table 6 within Paper A2**
1.3	10 Jul '11	Relations	New relations added Some relations modified or removed Relations are presented through a two-column table to represent both active and passive voices
		Attributes	Added Preposition, Relevance, Time, Cost and Location as new or separate Attribute
			Renamed Text to Description, Category to Type
		Concepts	Renamed Actors to Players
			Added Agents
1.4	17 Nov '11	Views	Added Knowledge Tools as a new view
		Concepts	Added Artefacts as a new concept
		Relations	Added and modified many relationships
1.5	24 Mar '13	Introduction	Modified introductory text
		Versioning	Changed version numbering from alphanumeric to numeric…V1F is now V1.5
1.6	9 Jun '13	Introduction	Updated for submission as an appendix to the PhD thesis
		Relations	Removed passive voice
1.7	17 Jun '13	Introduction	Minor text refinements
2.0	13 Dec '13	All	A major ontological realignment with the BIM Framework
		Concepts	An overhaul of concepts to match the BIM Framework
			Concepts are now referenced in singular tense
			Links to Knowledge Models are added
		Attributes	Replaced Relevance with Grade
			Replaced Number with Count
			Added Grade, Order and State
			Modified the description of all attributes – unified syntax
		Views	Merged Knowledge Matrix with Knowledge Document
			Calibrated the description of all Knowledge Views
2.0	13 Dec '13		**Published as Appendix A of the PhD Thesis**

V.	Date	Applies to	Description
2.1	15 Aug '15	Concepts	Clarified sub-concepts
			Added Conception; Conceptual Construct; Designation; Effect; Hardware; Proof; Measurement; Medium; Method; Model Use; Representation; Rule; System; Target; Test
			Removed Artefact; Field; Certificate; Metric; Organizational Unit; Sample; Social Value; Workbench
			Replaced Results with Result; Constraints with Constraint;
		Objects	Major re-alignment with the BIM Excellence method – now both the BIM Framework and BIM Excellence Method use the Conceptual BIM Ontology (v2.2 and up)
			Renamed Knowledge Views to *Knowledge Sets*
			Differentiated between lower and higher-level Knowledge Objects
		Subjects	Added a note in the introduction covering Knowledge Subject (the human actor)
		Sets	Renamed Knowledge Model to *Knowledge Foundations*
			Renamed Knowledge Store to *Knowledge Views*
			Added *Knowledge Blocks*
			Added *Knowledge Routines*
		Relations	Added Gathers; Visualizes; Determines
		Attributes	Added *Availability, Language* and *Market*
3.0	16 Aug '15		**Published on BIMframework.com** (link)
3.01	31 Aug '16	Concepts	Added *Scenario*, *Model* and *Information Use*
			Removed *Model Use*
3.02	28 Jun'16	Concepts	Reinstated *Model Use* (but kept *Information Use* which initially replaced it)
			Added *Document Use*, *Data Use*, *Facility*, *Lesson*, and *Responsibility*
		Concepts	Change Conceptual Construct to Conceptual Structure
3.1	28 Jul' 16	Sets	Renamed Knowledge Routines to Knowledge Workflows
		Concepts	Added Standards, Routines
3.11	21 Aug' 16	Concepts	Added *Format* and *Equipment*
3.12	23 Jan' 17	Relations	Removed the 'active' tone from all Relations
		Relations	Added *Affect* and *Verify*
		Concepts	Added *System Unit*
		Concepts	Change Conceptual Structure to Conceptual Construct – Conceptual Structure now refers to a combination of Conceptual Constructs
3.20	28 July' 17		**Formatting and minor text changes – the Conceptual BIM Ontology released as a resource of the BIMe Initiative**
3.21	14 Dec' 17	Attribute	Added 'Size' which was placed in error under 'Relations'
		Relations	Removed 'Size'
3.22	19 Jan' 18	Relations	Organise Relations under alphabetical headings
		Relations	Added 'Archive', 'Decommission', 'Delete', 'Digitise, 'Discard', 'Dispose', 'Edit', 'Extend', 'Harmonise', 'Keep Current', 'Print', 'Provide Access', 'Request', 'Represent'. 'Retrieve', 'Store', 'Synchronise', and 'View'

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V. References

Cottam, H. (1999). *Ontologies to Assist Process Oriented Knowledge Acquisition (Draft)*. Retrieved from https://link.springer.com/chapter/10.1007%2F978-1-4471-0745-3_16 Last accessed Jun 28, 2017

Gruber, T. R. (1995). Toward principles for the design of ontologies used for knowledge sharing? *International journal of human-computer studies, 43*(5-6), 907-928.

Milton, N. R. (2007a). *Knowledge Acquisition in Practice: A Step-by-step Guide*: Springer, London.

Milton, N. R. (2007b). Specification for the General Technological Ontology (GTO). Retrieved from http://www.pcpack.co.uk/gto/notes/files/GTO%20Spec%20v4.doc

Noy, N. F., & McGuinness, D. L. (2001). Ontology Development 101: A Guide to Creating Your First Ontology. Retrieved from http://www.lsi.upc.edu/~bejar/aia/aia-web/ontology101.pdf

Shanks, G., Tansley, E., & Weber, R. (2003). Using ontology to validate conceptual models. *Communications of the ACM, 46*(10), 85-89. doi:10.1145/944217.944244

Studer, R., Benjamins, V. R., & Fensel, D. (1998). Knowledge engineering: Principles and methods. *Data & Knowledge Engineering, 25*(1-2), 161-197.

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

Succar, B., Sher, W., & Aranda-Mena, G. (2007). *A Proposed Framework to Investigate Building Information Modelling Through Knowledge Elicitation and Visual Models*. Paper presented at the Australasian Universities Building Education (AUBEA2007), Melbourne, Australia. http://aubea.org.au/ocs/viewpaper.php?id=15&cf=1

Sugumaran, V., & Storey, V. C. (2002). Ontologies for conceptual modeling: their creation, use, and management. *Data & Knowledge Engineering, 42*(3), 251-271. doi:http://dx.doi.org/10.1016/S0169-023X(02)00048-4