A Proposed Framework To Investigate Building Information Modelling Through Knowledge Elicitation And Visual Models

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A PROPOSED FRAMEWORK TO INVESTIGATE BUILDING INFORMATION MODELLING THROUGH KNOWLEDGE ELICITATION AND VISUAL MODELS

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ABSTRACT

Building Information Modelling (BIM) is an expansive knowledge domain within the Architecture, Engineering and Construction (AEC) industry. To allow a systematic investigation of the domain, research is needed to define BIM knowledge components, connect its divergent fields and delineate its expanding boundaries. This paper introduces a research framework for identifying BIM concepts and a methodology for capturing and representing BIM interactions. It also proposes visual models to elicit expert knowledge and identifies further research requirements.

1 BUILDING INFORMATION MODELLING

Building Information Modelling (BIM) is a set of interacting policies, processes and technologies producing a "methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Penttilä, 2006).

1.1 BIM: the term

Building Information Modelling (BIM) is an emerging technological and procedural shift within the Architecture, Engineering and Construction (AEC) industry. Researchers have been investigating the components and repercussions of building product models (Eastman, 1999) for many years before the emergence of BIM as a new term. While the mere presence of a label or an acronym is viewed by some researchers as a sign of poor lexical literacy (Santini, 2002), others refer to names as “vital for communication and useful for understanding a situation” (Bono, 1970). Many industry writers and analysts have contested the many terms available while others have argued for the acceptance of BIM *as is* because of its adoption by industry’s major CAD developers (Liaserin, 2002). Whether the term itself is useful, agreed upon or contested, BIM is continuing its proliferation in both industrial and academic circles as the ‘new CAD paradigm’ (Ibrahim, Krawczyk and Schipporeit, 2004).

1.2 Differences between terms

Some researchers have opted to differentiate between the many available terms (Lee, Wu, Aouad, Cooper and Tah, 2005) but the extensively overlapping boundaries render the uniqueness of each term questionable. From conceptual to descriptive in nature, these terms can be attributed to research or industry bodies as well as software developers. Table 1 conveys the more widely used terms in both research and industry literature while Figure 1 represents common connotations of BIM terms.

Sample Terms	Organisation or Researcher	Reference
Asset Lifecycle Information System	Fully Integrated & Automated Technology	(FIATECH, 2005)
Building Information Modelling	Autodesk and Bentley Systems	(Autodesk, 2005) (Bentley, 2006)
Building Product Models	Charles Eastman	(Eastman, 1999)
BuildingSMART™	International Alliance for Interoperability	(IAI, 2005)
nD Modelling	University of Salford – School of the Built Environment	(Lee, Wu, Marshall-Ponting, Aouad, Cooper, Koh, Fu, Betts, Kagioglou and Fischer, 2003)
Virtual Building™	Graphisoft	(Graphisoft, 2006)
Virtual Design and Construction & 4D Product Models	Stanford University– Center for Integrated Facility Engineering	(Fischer and Kunz, 2005) (Fischer, 2001)
Other terms: Integrated Model, Object Oriented Building Model, Single Building Model,…		

Table 1: terms used by researchers, institutions and organisations to describe the Building Information Model

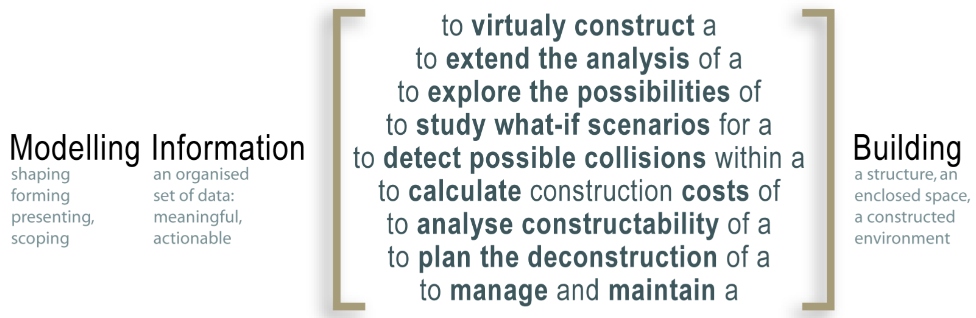

Figure 1: some of the common connotation of multiple BIM terms

Some of the underlying knowledge and computational structures represented by these terms has shifted from research circles to the industrial realm (Khemlani, 2005) while many efforts could not gain the interest of the industry (Halfawy and Froese, 2002).

1.3 The need for a framework

In many writings, seminars and workshops, BIM is argued to be a catalyst for change (Bernstein, 2005) poised to reduce industry's fragmentation (CWIC, 2004), improve its efficiency/effectiveness (Hampson and Brandon, 2004) and lower its high costs of inadequate interoperability (NIST, 2004). These assertions –abridged as they may be- include several mental constructs derived from organisational studies, information systems and regulatory fields. Such divergence and coverage highlights the *lack of* and the *necessity for* a research framework requiring systematic investigation of the BIM domain. The availability of a framework will assist in organising domain knowledge, elicit tacit expertise and facilitate the creation of new knowledge.

2 PROPOSED RESEARCH FRAMEWORK

This paper proposes a prototypical framework and an investigative methodology to identify, capture and represent BIM interactions. The framework (Table 2) is composed of three interlocking knowledge nodes (Figure 2) and their push-pull interactions (Figure 3).

2.1 The BIM Policy node

The first node is the field of interaction generating research frameworks, standards and best practices for the purpose of safeguarding benefits and minimizing conflict between BIM stakeholders

2.2 The BIM Process node

The second node is the field of interaction between construction requirements, construction deliverables, organisational structures and operational communications for the purpose of generating and maintaining building information models.

2.3 The BIM Technology node

The third node is the field of interaction between software, hardware and networking systems necessary to generate and maintain building information models.

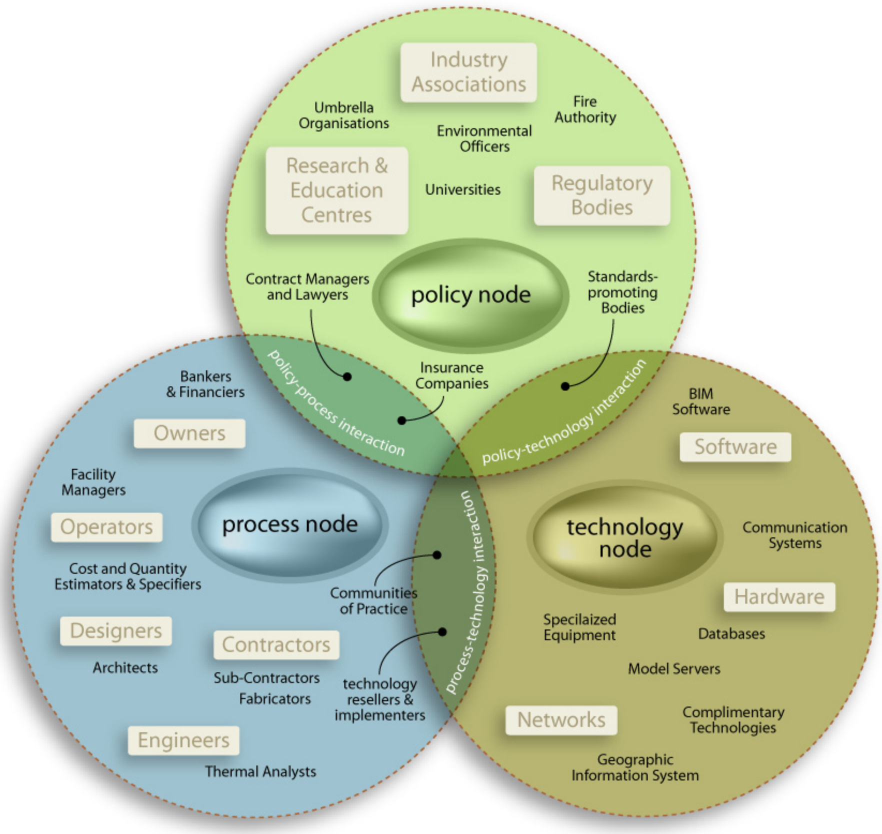

Figure 2: the proposed BIM research framework includes three interlocking knowledge nodes

		Policy node	Process node	Technology node
Definition		Policies are "written principles or rules to guide decision-making" (Clemson, 2007)	Process is "a specific ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs: a structure for action" (Davenport, 1992)	Technology is "the application of scientific knowledge for practical purposes" (Oxford, 2007)
Extended node Definition		The field of interaction generating research frameworks, standards and best practices for the purpose of safeguarding benefits and minimizing contestation between BIM stakeholders	The field of interaction between construction requirements, construction deliverables, organisational structures and operational communications for the purpose of generating and maintaining the building information model (BIModel)	The field of interaction between software, hardware and networking systems necessary to generate and maintain the BIModel
Node participants		Governments, researchers, industry associations, insurance companies and regulatory bodies	Owners, operators, designers, engineers and contractors	Software, hardware and networking companies plus their development and sales channels
BIM deliverables		Policy guideline standards best practices bench marks contracts	Projects Structures	Software tools Computers & peripherals Collaborative tools
BIM Interactions	**Push**	BIM deliverables into the process node	Case studies into the policy node.	Innovative solutions into the process and policy nodes
	Pull	Information from the process node	Development of solutions from the technology node. standardisation from the policy node	Standardisation efforts from the policy node

Table 2: proposed BIM research framework

2.4 BIM interactions

BIM interactions (Figures 3) are push-pull knowledge transactions within and between BIM nodes. Push mechanisms (Holsapple and Joshi, 2006) transfer knowledge to another node or sub-node while pull mechanisms transfer knowledge to satisfy a request by another node or sub-node. Sample transactions include data transfers, team dynamics and contractual relationships between nodes and sub-nodes. The acquisition and representation of these interactions are the research deliverables of the proposed framework.

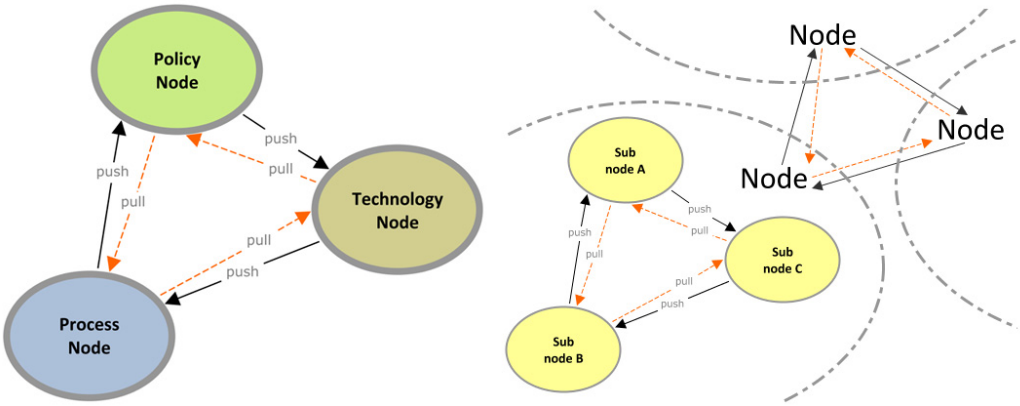

Figure 3: BIM interactions within and between framework nodes

3 CAPTURING AND REPRESENTING BIM INTERACTION

Knowledge capturing and representation activities involve the identification and acquisition of knowledge within the environment under investigation then making it available in a representation suitable for generalisation and dissemination (Holsapple and Joshi, 2006) (Holsapple and Jones, 2006).

Driven by the expanse of knowledge domains covered by the BIM research framework, the knowledge transactions are necessarily numerous and complex in nature. Such a wide and varied scope of interactions necessitates the use of visualisation to cope with the amount and complexity involved (Tergan, 2003). Representing and visualising these interactions offers a systematic way to transfer this knowledge to others (Eppler and Burkhard, 2005).

3.1 Proposed methodology to identify, capture and represent BIM interactions

This paper proposes a six-stage methodology to define, capture and represent BIM interactions through knowledge elicitation and visual knowledge models (refer to Figure 4). In the sections that follow, the first two stages are discussed and examples are provided. The remaining stages are outside the scope of this paper and are thus briefly defined.

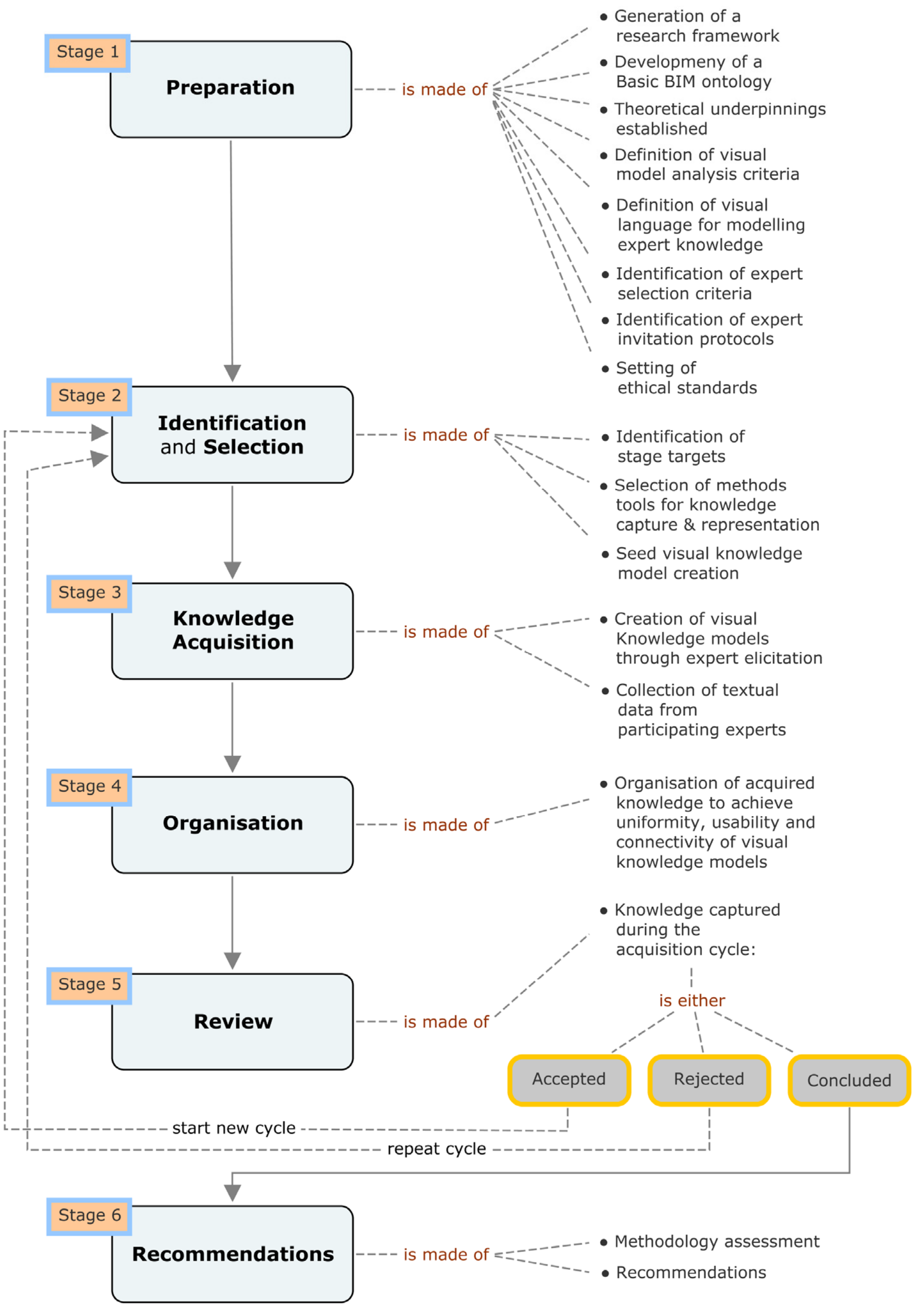

Figure 4: proposed methodology to identify, capture and represent BIM interactions

3.1.1 Stage 1: Preparation Stage

The preparation stage defines the scope of the research, generates a basic BIM ontology and discusses theoretical underpinnings, tools and research protocols.

Scope

Research scope is governed by the BIM framework introduced earlier. The framework is an attempt to organise the expanding number and complexity of BIM concepts. The framework proposes three interlocking BIM knowledge nodes and investigates the interactions within and between them.

Ontology

BIM interactions form the basis for a general BIM ontology generated through an initial seven-step approach (Noy and McGuinness, 2001). At this preparatory stage, researchers will generate a high-level formal ontology of BIM interactions and then subdivide it into lower level taxonomies and partonomies (Buchholz, 2006). The partonomies will be formalised interdependently through knowledge acquisition and representation (Stage 3) forming a facilitative basis for other acquisitions (Holsapple and Joshi, 2006) . The subdivision is intended to reduce domain complexity and allow the concurrent capture of different ontological parts.

Selection protocols

BIM interactions are complex, expansive and multi-disciplinary in nature. Capturing and representing domain knowledge necessitate the participation of both researchers and practitioners. Selection and invitation protocols of subject matter experts (SMEs) are set during this stage.

Theoretical underpinnings

The preparatory stage identifies theoretical underpinnings of knowledge capture and representation. It also defines model analysis, acceptance and rejection criteria required for the review stage.

Ethical issues

Ethical issues pertaining to expert selection and knowledge elicitation are defined.

Visual language

"Graphics is a tool that obeys universal laws that are unavoidable and undisputable but can be learned and taught"(Bertin, 1997). The preparatory stage will identify the graphical language and tools suitable to capture and visualize domain knowledge.

Definition of visualisation

Visualisation utilizes graphical means to explore, communicate or resolve logical problems (Card and Mackinlay, 1997). Visualisation can generate models in different formats (Figure 5) but share the intent to communicate and re-construct meaning (Eppler and Burkhard, 2005).

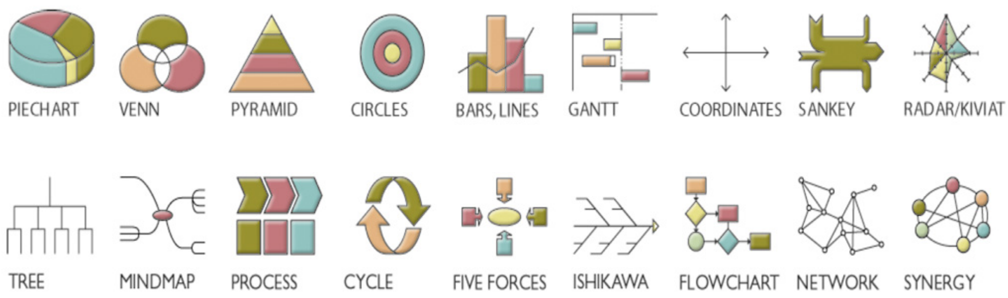

Figure 5: sample visualisation models – adopted from Eppler and Burkhard, 2005

Each model format offers a unique way to represent meaning. The VENN format (Figure 5) for example, is appropriate to represent overlapping BIM nodes while maps are better suited to capture and represent BIM interactions.

Visualisation types

Graphical representations can be subdivided into two distinct areas of research: Information Visualisation and Knowledge Visualisation (Keller and Tergan, 2005). The differences between the two visualisation approaches are summarised in Table 3 below:

<table>
<tr><th colspan="3">Information Visualisation</th><th colspan="3">Knowledge Visualisation</th></tr>
<tr><td colspan="3">Information Visualisation is the computer-assisted visual processing to gain understanding of data relations (Card and Mackinlay, 1997)</td><td colspan="3">Knowledge Visualisation focuses on knowledge discovery, representation and augmentation without being limited to computer-assisted formats (Eppler and Burkhard, 2005).</td></tr>
<tr><td colspan="3">Information visualisation has its origin in computational sciences (Keller and Tergan, 2005)</td><td colspan="3">Knowledge visualisation has it origins in social sciences (Keller and Tergan, 2005)</td></tr>
<tr><td colspan="3">Information Visualisation aims to reveal relationships between data</td><td colspan="3">Knowledge Visualisation aims to reveal relationships between information</td></tr>
<tr><td colspan="6">The semantic differences between data, information and knowledge can be summarised as follows:</td></tr>
<tr><td colspan="2">Data are observations and collectibles; data is what can be seen and collected (Landauer, 1998). Data is a raw symbol that has no meaning in itself and has no significance beyond its existence (Keller and Tergan, 2005)</td><td colspan="2">Information represents connected data whether to other data or to a context; information is what can be expressed (Landauer, 1998). Information conveys different meanings to different persons (Keller and Tergan, 2005).</td><td colspan="2">Knowledge sets a goal for information and is an expression of regularity (Landauer, 1998). Knowledge exists as part of a person, a group or a society’s cognition (Keller and Tergan, 2005).</td></tr>
</table>

Table 3: visualisation approaches and their semantic differences

Building Information Modelling includes transactions at the *data*, *information* and *knowledge* semantic levels (refer to Table 4). Representations of BIM interactions fall within the research area of knowledge visualisation; a merger between information visualisation, didactic techniques, visual cognition and visual communication (Eppler and Burkhard, 2005).

3.1.2 Stage 2: Identification and selection

This stage identifies the ontological part to be subsequently investigated in stage 3. Methods and tools best suited to conduct this investigation are selected. Stages 2, 3 and 4 are iteratively repeated to investigate other parts of the ontology within the research scope.

Identification of stage target

A target is identified for each cycle: a node, sub-node or a set of BIM interactions semantically linked within the ontology.

Selection of methods and tools

After the stage target has been identified for each cycle, methods and tools for knowledge elicitation and representation are selected.

As an example, this paper discusses map-based visualisation as a means for knowledge acquisition and representation:

Knowledge acquisition through map-based visualisation

According to Tergan (2003), map-based visualisation is a "valuable cognitive tool for supporting knowledge use in a variety of learning and instructional settings". Map-based visualisations include concept, mind and other node-link-label maps (Figure 6).

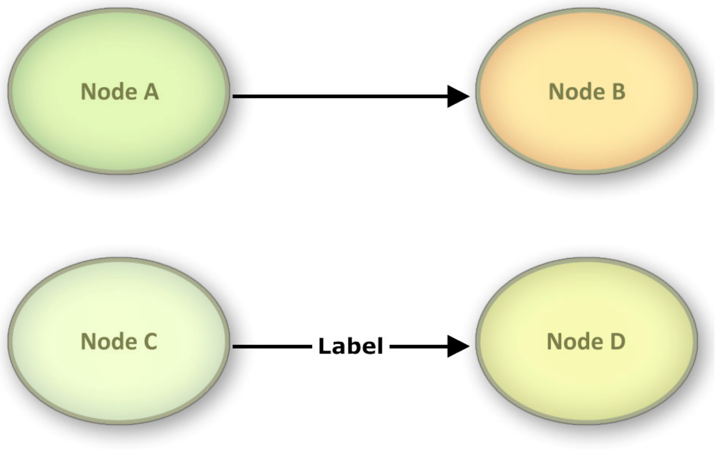

Figure 6: node-link-label maps

A summary of benefits and limitations pertaining to map-based visualisation (Tergan, 2003) (Eppler and Burkhard, 2005) are provided in Table 4:

Benefits	**Risks and limitations**
Assessing structural knowledge	Confusing or ambiguous visuals
Concept acquisition	Information overload
Brainstorming of ideas	Misrepresentation of concepts
Scaffolding cognitive processes in knowledge acquisition and problem solving	Oversimplification of represented concepts
Self-regulated learning	Overuse
Knowledge communication & coordination	Deliberate manipulation
Draw attention by identifying patterns	Difficult to create
Improve remembrance/recall	Difficult to maintain
Act against information overload	

Table 4: benefits and limitations of map-based visualisation

Of the many types of map-based visualisation, “concept maps made by domain experts tend to show high levels of agreement” (Hoffman and Lintern, 2006). Accordingly, this paper proposes the use of concept maps for knowledge elicitation and representation.

Using concept maps for knowledge elicitation and representation

Concept mapping, a node-link-label format, was invented in 1972 to describe explicit changes in conceptual understanding. In 1987, Concept Maps (CMaps) were first used in knowledge elicitation and as a web-based mapping application (Novak and Cañas, 2006).

Similar to cognitive maps and semantic networks (Jonassen, 2005), CMaps link concepts (nodes) together using words or phrases (labelled links) to create propositions (Figure 7).

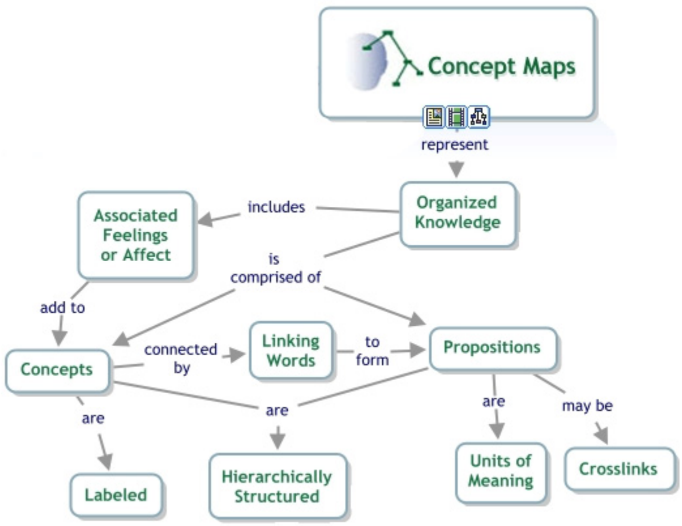

Figure 7: CMap Tools – a concept map about concept maps (Novak, 2003)

CMaps are based on explicit cognitive psychology and constructivist epistemology (Novak and Cañas, 2006). Many studies have shown CMaps’ utility in capturing knowledge and eliciting explanations (Derbentseva, Safayeni and Cañas, 2007). This paper proposes the use of concept maps as part of a methodology to elicit and represent BIM expertise.

Using a seed model

The generation of new knowledge models will depend on the critical understanding of existing models (Davenport, 1992). A seed model will be based on literature, industrial prototypes and knowledge pushed from previous cycles (example - Figure 8). It may be created at each iteration to assist in eliciting expertise and generating new models.

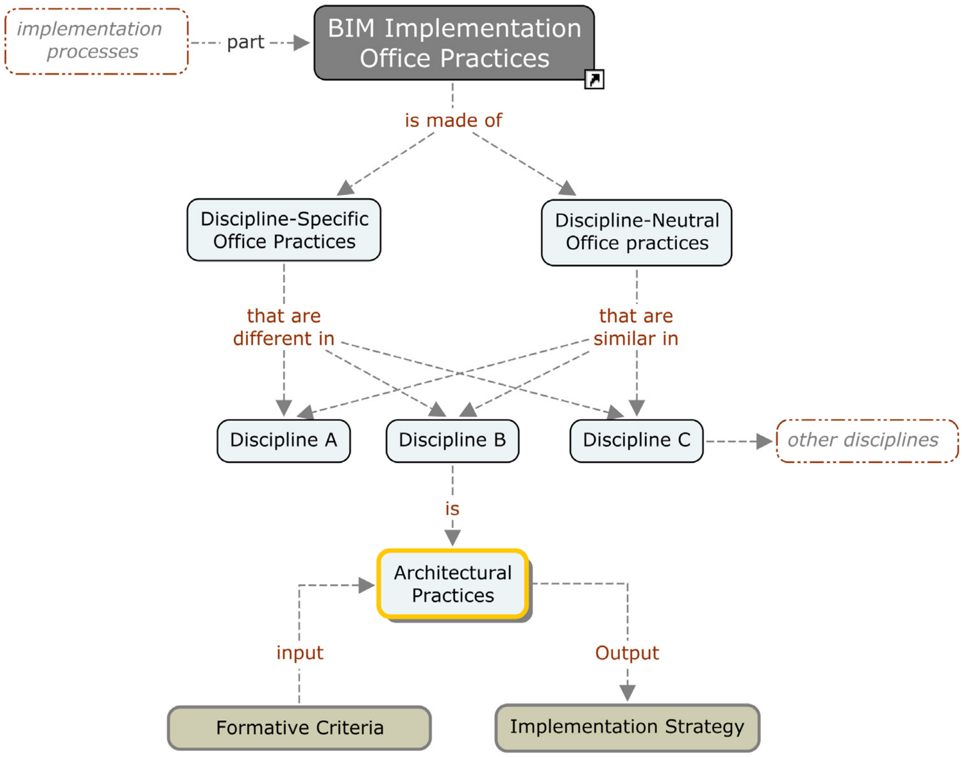

Figure 8: sample Seed model - "BIM Implementation - Office Practice"

Map-based visualisation is one method of capturing and representing expert knowledge. Other methods include jointly-authored web spaces allowing research participants to add, remove or edit content (Wikipedia, 2007).

The ontological part identified in stage 2 will drive acquisition and representation methods in stage 3.

3.1.3 Stages 3 to 6: acquisition, organisation, review and recommendations

The following stages are outside the scope of this paper and will be briefly discussed in the sections below. More research is needed to formalise the methods and tools necessary to capture and then organise knowledge in accordance with the high-level ontology and its subdivisions (identified in Stage 2).

Knowledge acquisition is a process to generate qualitative models of systems, whether social or technological. It is not the mere extraction of facts and rules from literature or experts' minds (Clancey, 1993). In Stage 3, knowledge is elicited from experts using shared visual models. Elicitation is driven by ontological identifications performed at Stage 2. Experts and researchers will jointly build knowledge models comprising explicit representations of domain interactions (Ford, Bradshaw, Adams-Webber and Agnew, 1993).

In Stage 4, the captured knowledge from each cycle is organised around the research framework then prepared for review and analysis. Uniformity, usability and connectivity of knowledge models are the main deliverables of this stage.

In Stage 5, the knowledge models are analysed to detect and then amend inconsistencies within the research framework, methodology or ontology. Subject to analysis criteria defined in Stage 1, resultant model from each research cycle will be accepted or rejected. Rejected cycles get repeated (refer to Figure 4) while accepted models get used as seed models for consequent cycles.

The investigation concludes in Stage 6 when research scope, defined in Stage 1, has been fulfilled. Resultant knowledge models are published, methodology is discussed and recommendations for further research are provided.

4 CONCLUSION

Building Information modelling is an expanding field of study incorporating many knowledge domains within the Architecture, Engineering and Construction industry. The divergence of study topics relating to BIM highlights the *lack of* and the *necessity for* a research framework allowing its systematic investigation. This paper has proposed a prototypical framework and an investigative methodology to identify, capture and represent BIM interactions. The framework is composed of three interlocking knowledge nodes: policy, process and technology. The methodology includes six stages to elicit expert knowledge through visual knowledge models within a proposed BIM ontology. Graphic representations have been surveyed and map-based visualisation has been identified as an appropriate method for knowledge elicitation. Knowledge acquisition, knowledge organisation and respective tools have been identified for further research.

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