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2019

Network FOuNTAIN

A CDBB Network: For ONTologies And Information maNagement in Digital Built Britain

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Final Report, January 2019

Executive Summary

Network FOuNTAIN is the Network For ONTologies And Information maNagement in Digital Built Britain. The Network is supported by the Centre for Digital Built Britain. The vision of the Network is for all stakeholders in Digital Built Britain (DBB) to be able to meet their information needs. With the establishment of concepts such as Building Information Modelling (BIM) and Common Data Environments (CDE), built environment design, construction and operation are becoming increasingly information-intensive.

The Network undertook five workshop activities between July and December 2018. This report summarises the proceedings of these workshops, and in particular establishes future capabilities needed to realise the vision of DBB. The table below summarises the workshops, maps their topics to the Information Management Landscape from West and Cook (2018), and presents the capabilities needed in DBB.

Workshop	Leader	Issues Discussed	Elements from Information Management Landscape Addressed	Capabilities
Workshop 0: Scope of Information Management	Matthew West, Information Junction	Information Management Landscape, Information Management Maturity.		Capability to gauge Information Management maturity.
Workshop 1: Ontologies	Professor Stuart Barr, Newcastle University Dr Tom Beach, Cardiff University	Variety of ontologies, standardisation vs. flexibility.	"Industry Architecture Standards for Information"	Capability to establish the appropriate scope of standardisation, and to design or extend existing *ontologies in general*.
Workshop 2: Cataloguing Information	Dr Steven Yeomans, Loughborough University	Delphi Survey to achieve expert consensus on most suitable, adaptable and complete ontology and project process to be used for cataloguing information in DBB. There was no full consensus, but Uniclass-2015 stood out as a candidate.	"Industry Architecture Standards for Information"	Capability to develop current classification systems, schema and frameworks, Uniclass-2015 *in particular*, to maximise the potential to share data, in ways that make best use of current skills and investments
Workshop 3: System Requirements	Dr Peter Demian, Loughborough University	Search & Retrieval, Browsing & Exploration, Information Delivery as models for information consumption in DBB.	"Information Use"	Capability to develop fit-for-purpose software which enables stakeholders • to query information repositories visually or using natural language • to explore information repositories based on current models (such as Uniclass-2015) • to interrogate information repositories automatically using ontology-based tools, and • to set information delivery schedules based on industry and project protocols
Workshop 4: Business Models	Dr Mohamad Kassem, Northumbria University	The need for a process model for delivering business value through Information Management.	"Industry Process Model"	Capability to identify and derive business value from Information Management.

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1 Introduction to Network FOuNTAIN

Network FOuNTAIN is the Network For ONTologies And Information maNagement in Digital Built Britain. The Network is supported by the Centre for Digital Built Britain. The vision of the Network is for all stakeholders in Digital Built Britain (DBB) to be able to meet their information needs. With the establishment of concepts such as Building Information Modelling (BIM) and Common Data Environments (CDE), built environment design, construction and operation are becoming increasingly information-intensive.

The Network undertook five workshop activities between July and December 2018. The purpose of those workshops was to:

(0) Scope out the issue of Information Management in DBB;
(1) Explore ontologies to extract information from data;
(2) Catalogue the types of information to be managed in DBB;
(3) Specify software requirements for tools to manage this information
(4) Investigate an approach to formulate a process model for delivering value from information management.

This report presents the outcome of those activities. A full report from each workshop is included as Appendices A-E. An attempt is made to draw out capabilities required by the UK to deliver a Digital Built Britain. Those capabilities are collated in Appendix F.

2 Scope of Information Management

The full report from Workshop 0 is included here as Appendix A. That first workshop was led by Matthew West of Information Junction, focused on *the scope of Information Management*, and attempted to establish a theoretical lens through which the subsequent work of the Network could be managed. It was noted that the value of information comes from its use in supporting decisions. Information Management is about ensuring that the right information is delivered at the right time to the right people. *Quality* means meeting requirements agreed between information users and suppliers.

2.1 Information Management Landscape (IML)

The Information Management Landscape found in the White Paper by West and Cook (2018) was discussed at the workshop and informed the subsequent Network activities. That publication uses examples to illustrate the capability required for data integration, and identifies the elements of an Information Management Landscape (IML) required to deliver that capability, as shown in Figure 1.

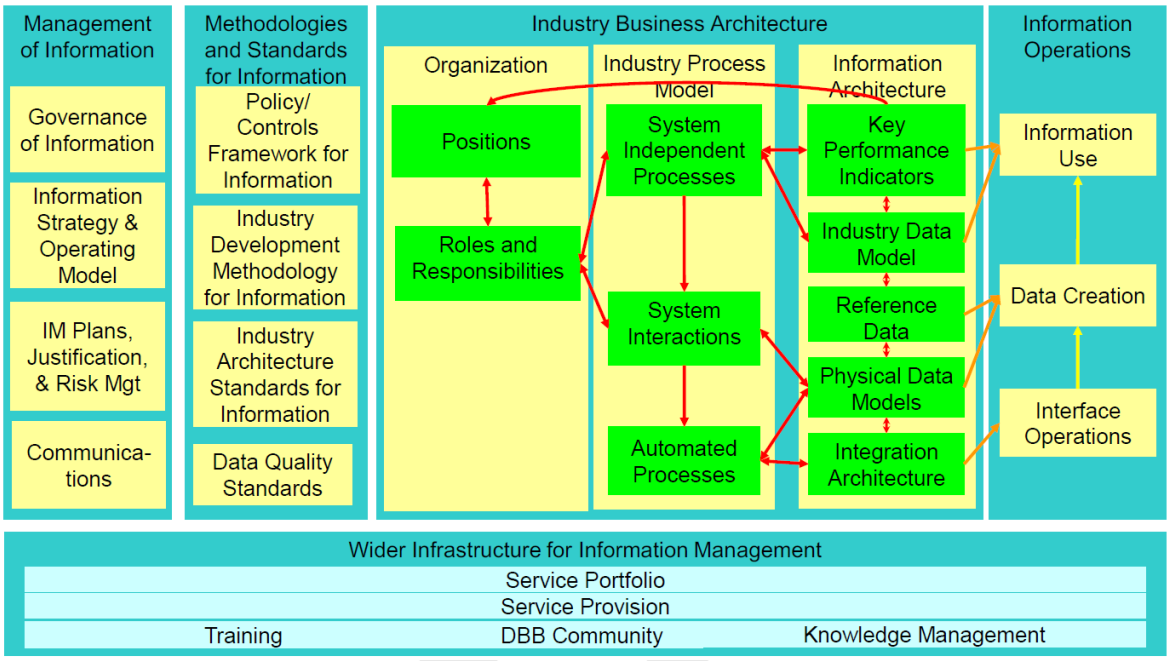

Figure 1: Information Management Landscape (West and Cook 2018)

The IML proved to be a useful guide for planning and managing the subsequent activities of the Network. Workshop 1 on Ontologies and Workshop 2 on Cataloguing Information both addressed the "Industry Architecture Standards for Information" element. Workshop 3 on System Requirements addressed the "Information Use" element. Workshop 4 on Business Models addressed the entire "Industry Process Model" block. Section 2.3 describes an exercise whereby Workshop 0 attendees were asked to map their current research to the IML (with full details in Appendix A).

It is noteworthy that ISO19650 Part 1 (ISO 2018a) provides an alternative representation of the Information Management domain specifically for the built environment. It refers to the purpose of information, and defines *trigger events* and *key decision points* where an *information requirement* might arise.

2.2 Information Management (IM) Maturity

IM Maturity can be broken down into five stages: *Initial*, *Recognising*, *Specifying*, *Managing* and *Optimising*. Workshop attendees discussed the maturity of the industry as a whole, and of particular groups or organisations. At the publication of the Latham Report in 1994, the industry was considered to be still at the *Initial* stage. The Avanti case study in 2007 perhaps signalled *Recognising* maturity. The release of COBie and the emergence of the concept of Open BIM signal important milestones in UK industry Information Management maturity, but formal classifications are difficult.

No clear consensus was reached regarding IM maturity of companies. Attendees agreed that the client is the most important "organisation" to drive maturity, pushing

the IM agenda or pulling the information it needs. Generally, the views from the workshop suggest that many organisations are at *Specifying* level.

ISO19650 Part 1 (ISO 2018a) gives an alternative classification of IM maturity, (again specifically for the built environment, or the adoption of BIM) broken down into three Stages, which supersedes the BIM Levels of the classic Bew-Richards "wedge" (CIOB 2018).

Capability 0: Capability to gauge Information Management maturity, as part of existing standards or new standards.

2.3 Current Information Management Research

As an indicative "snapshot" of current IM research, attendees of Workshop 0 were asked to map their research activities against the elements of the IML. The results can be seen in Figure 3 (part of the Workshop 0 report in Appendix A). The nested nature of the IML elements prevents meaningful identification of research gaps. It appears that the "Industry Data Model" element is receiving research interest. The work of Network FOuNTAIN, and particularly of Workshop 2, add to this. As a snapshot of the research gaps in the work of attendees' organisations in August 2018, the following elements had no research activities mapped to them:

- 1 Management of Information
- 1.3 IM Plans, Justification, & Risk Management
- 1.4 Communications
- 2.1 Policy/ Controls Framework for Information
- 2.2 Industry Development Methodology for Information
- 2.3 Industry Architecture Standards for Information
- 3 Industry Business Architecture
- 3.1.1 Positions
- 3.3 Information Architecture
- 3.3.1 Key Performance Indicators
- 3.3.4 Physical Data Models
- 3.3.5 Integration Architecture

Capability 0 set out above can be mapped to 3.3.1. Capabilities 1a,1b,2,3 and 4 set out below can be mapped to IML elements 1.2, 2.2, 2.2, 4/4.1/4.3 and 1/3 respectively (IML elements numbered in Figure 3 on page 18).

3 Ontologies

The full report from Workshop 1 on Ontologies is included here as Appendix B. The workshop was led by Professor Stuart Barr of Newcastle University and Dr Tom Beach from Cardiff University. An "Ontology Tutorial" was presented, followed by a session where several attendees presented case studies of how ontologies were used in their professional practice. The workshop closed with a discussion of the current industrial/academic use of ontologies, gaps in the state-of-the-art and opportunities for

future development. The focus of that Workshop 1 on Ontologies corresponds to the "Industry Architecture Standards for Information" element of the Information Management Landscape (Figure 1, page 5).

3.1 Fundamentals of Ontologies

Ontologies are a formal, standard representation of objects, their attributes and relationships between these objects. This representation is often used for reasoning. S*chemas* are similar to ontologies, but schemas are often created for the purpose of designing database systems, and so their emphasis is on storing and querying datasets, rather than reasoning. *Standardisation* is an inherent characteristic of ontologies.

The main theme which emerged from that part of the workshop is the *tension between standardisation and flexibility*. A balanced approach is to standardise common aspects and allow users to extend bespoke aspects. Too little standardisation means high flexibility for all stakeholders but can result in poor interoperability between stakeholders (no common language). Too much standardisation results in inflexibility and risks stakeholders not using the ontology. The balance can be expressed in terms of "standardising the right things", rather than too much or too little standardisation. This is set out in Capability 1a below. It is noteworthy that *Uniclass-2015* was identified as having a significant following and value to the practitioner community. Like several of the standards cited at that workshop, Uniclass-2015 can be argued to be a classification system rather than an ontology in the strict sense. In some applications, the ISO15926 series of standards has been found to offer more flexibility than Uniclass-2015 in terms of object attributes (BIM4Water 2017). Uniclass-2015 has been restructured and redeveloped to provide a comprehensive system suitable for use by the entire construction industry and for all stages in a project life cycle (NBS 2018a). Despite aspects of extensibility, the fact that objects could only be classified in a single way in Uniclass was considered a weakness. It is important that any approach to ontology development give due consideration to valued current tools, for example Uniclass-2015, exploring ways to integrate available insights and best use current investments and skills.

Capability 1a: Capability to establish the appropriate scope, priorities and pace of standardisation, at *industry*, *project* and *organisation* levels.

3.2 Ontological Issues faced by the Industry

In addition to the issue of standardisation vs. flexibility outlined above, the following issues emerged from the discussion:

- "Principles" need to be established at the outset, before designing or adopting an ontology? What are the needs and purposes of information creators, managers, users?

- Clarity is needed regarding the nature of existing standards. Are they ontologies (ifcOWL), schemas (IFC, CityGML), or classification systems (Uniclass-2015, COBie) and therefore what might be their role in future?
- What are the strengths and weaknesses of candidate ontologies? [This issue was addressed in the subsequent Workshop 2.]
- What is the appropriate scope of an ontology: buildings, cities, infrastructure, linear infrastructure? Is it required or reasonable for a single ontology to cover all? [This issue overlaps somewhat with the issue of standardisation vs. flexibility outlined in section 3.1 and addressed in Capability 1a.]

The discussion from that part of Workshop 1 can be distilled in Capability 1b:

Capability 1b: Capability to underpin data exchange and integration by developing an appropriate approach to develop new, to extend and adapt existing ontologies, and to create the means to integrate current schema and classifications. (A prescriptive process model is needed.)

4 Ontologies for Cataloguing Information

The original aim of Workshop 2 was to create a list (or catalogue) of all the various types of information that require managing in DBB. However, following a number of informative discussions at the earlier workshops, it became apparent that such listing might already exist in existing ontologies or standards. Instead, a panel of expert practitioners was surveyed to review current ontologies and standards, to investigate how they categorise information. The Delphi method was used through an online platform. Like Workshop 1 before it, the focus of Workshop 2 corresponds to the "Industry Architecture Standards for Information" element of the Information Management Landscape, and perhaps touches on the "Information Operations" block (Figure 1, page 5). The full report from Workshop 2 is included here as Appendix C.

4.1 Method

An initial desktop literature review was conducted to identify current ontologies or standards for Information Management in the built environment, a catalogue of information types, and a list of project processes within the current standards. The Delphi method was then applied in an attempt to achieve a reliable consensus from the panel of experts over two initial rounds of enquiry. Practitioners from the Network were invited to form the panel of experts. A third round was included to capture additional comments from the experts, as well as substantiate experts' key credentials. A summary of the results from the previous round was used to inform consensus building in the subsequent round. Participants were encouraged to review the anonymous opinions of all experts, before being provided with an opportunity to revise their previous response, thus supporting a more consensus-based conclusion.

The questionnaire contained four key sections:

Section 1: enquired about the suitability, completeness, and adaptability of current ontologies/standards, i.e. IFC, Uniclass-2015, COBie, CI/SfB and CityGML. Questions were assessed using a Likert Scale from 1 to 5.

Section 2: interrogated participants about the possibility of combining ontologies to obtain a more comprehensive information catalogue, as well as current and future trends that need to be addressed in DBB.

Section 3: asked the experts to define what are the most important types of information, through use of the classification taken from Uniclass-2015. Open-ended questions were then used to explore current and future trends in types of information.

Section 4: enquired about the suitability, completeness, and adaptability of current process models, namely, Construction Industry Council (CIC) Scope of Services, RIBA Plan of Work 2013, PAS1192:2 and the Government Soft Landings. Again, a Likert Scale from 1 to 5 was applied.

4.2 Findings

Experts could not reach *full* consensus on one particular ontology/standard generally being the most suitable. *However Uniclass-2015 did stand out as having a significant following and offering valuable attributes.*

Similarly, for the project processes, none attained the scores required for consensus to be decisively considered the most suitable, complete, and adaptable. *However the project processes of PAS1192:2 emerged as the most suitable and adaptable.*

The experts' opinions were also collected on what are the most important information types to be managed. The initial results are presented in Table 1 on page 25 (Workshop 2 report in Appendix C). "Asset information (maintenance, operations, performance)" was ranked top, with "Datasets (GIS dataset, information exchange file, room data sheet)" and "Record Information (certificate, forms, manual, plan, register, report)" in joint second. A final round of data collection is underway at the time of writing, with final analysis and dissemination planned in due course.

As for Workshop 1, the initial findings from Workshop 2 point to Uniclass-2015 as having significant (but not consensus) support, providing coverage of many of the needs of a candidate standard framework to share data. The results are yet to be fully analysed and compared to other studies (e.g. UIL 2018). Capability 2 can preliminarily be set out as follows:

Capability 2: Capability to develop current classification systems, schema and frameworks, Uniclass-2015 in particular, to maximise the potential to share data, in ways that make best use of current skills and investments.

5 System Requirements

The full report from Workshop 3 on System Requirements is included here as Appendix D. The purpose of that workshop was to explore the software requirements in BIM and CDE platforms, focusing on the consumption (as opposed to the production) of information. This focus corresponds to the "Information Use" element of the Information Management Landscape (Figure 1, page 5).

Three modes of interaction were presented: (1) Search & Retrieval, (2) Browsing & Exploration, and (3) Information Delivery. The choice between the three modes depends on the task at hand, the type of content (information) being managed and (most importantly) the user's awareness of his or her information need. If the user knows exactly what information is needed, he/she will be able to articulate a query, search and retrieve the required information. If the user is unsure exactly what information is needed, but has some notion of an information need, browsing and exploration might be more appropriate. If the user has no idea what information is needed, or is even unaware that there is a need for information or that useful content might be available, the system unilaterally delivering information to the user might be the most effective mode of interaction.

5.1 Search & Retrieval

Search & Retrieval is appropriate when the user is aware of the information need with some precision, and the nature and sheer scale of the information make it difficult to visualise the whole repository and explore it systematically. The example of the 3DIR project was presented at Workshop 3 (Demian *et al.* 2016). The task of *formulating queries* in Search & Retrieval received particular attention in the workshop discussion. Queries in a natural language would be extremely useful, as would query templates or a visual query language (akin to visual computer programming).

5.2 Browsing & Exploration

Browsing & Exploration is useful when the awareness of the information need is not precise enough to enable formulation of an explicit query. It might also be more effective when interacting with a moderately sized (rather than large) repository of information. Even though no explicit query is formulated, some data from the user's current task can be extracted and used as an implicit query, to highlight potentially relevant items in the repository. The "Shneiderman mantra" of "overview first, zoom and filter, and then details on demand" was cited (Shneiderman 1996). The CoMem project was presented as an example of this mode of interaction (Fruchter and Demian 2002).

From the discussion, Uniclass-2015 again emerged, this time as the most likely representation of practitioner's search models to structure Browsing & Exploration. The relative simplicity and hierarchical nature of Uniclass-2015 were both seen as

beneficial characteristics. Its limitations include its inflexibility and its poor coverage of infrastructure information.

5.3 Information Delivery

If the user has no idea what information is needed, or is unaware that useful content might be available, the system can unilaterally deliver information which might be deemed relevant based on an implicit query from the user's current work. In DBB, particular protocols require that information is delivered to particular stakeholders at particular times (for example, CDE Sub Group 2018), and this is a possible application of this mode. It was agreed this Information Delivery, sometimes considered disruptive, *did* have a place in CDE ad BIM platforms.

5.4 Software Requirements and Capabilities

The aim of Workshop 3 was originally to establish the software requirements for Information Management functionality in BIM and CDE platforms. The following functionality can be distilled from the discussion:

- Querying repositories using a visual syntax or the natural language used by stakeholders
- Browsing & Exploration of information repositories based on Uniclass-2015
- Information Delivery based on industry or project protocols

These functions can be framed as the following capability required by UK software developers for the sector:

Capability 3: The capability to develop fit-for-purpose software which enables stakeholders -to query information repositories visually or using natural language, -to explore information repositories based on current models (such as Uniclass-2015), -to interrogate information repositories automatically using ontology-based tools, and -to set information delivery schedules based on industry and project protocols.

The three modes of information consumption and the corresponding capabilities should enable the effective *finding* and *understanding* of information. These complement the Plain Language Question (PLQ) approach (NBS 2018b), whereby a client/employer poses questions at various decision points or construction stages. The NBS BIM Toolkit (NBS 2018c) includes a function for drafting PLQs and allocating them to project stages and appointments. The BIM Task Group gives a set of PLQs categorised across the project stages (BIM Task Group 2018). PLQs can be used as the mechanism to query or browse repositories, or drive the creation and delivery of information.

6 Business Models

The full report from Workshop 4 on Business Models is included here as Appendix E. Dr Mohamad Kassem from Northumbria University led a lively discussion of business process models and made a case for a value-driven ontology for business models under DBB. This focus aligns with the "Industry Process Model" block of the Information Management Landscape (Figure 1, page 5).

There was consensus that a systematic approach is needed for identifying and delivering business value (in broader terms, including social, economic and environmental value) from Information Management. The use cases explored by the attendees (the use of digital data to improve service delivery in healthcare infrastructure, and the use of digital data to improve the use/performance of equipment on site) highlighted the challenges of understanding how value can be created from managing digital data. There is a need for a systematic method to explore the value chain involved in creating and exchanging digital data to unlock business value. The merits of ontologies, business models, and process models in this context were discussed. It was concluded that a process model is needed for identifying and delivering business value through Information Management in DBB.

Capability 4: The capability systematically to identify and derive business value (including political, technological, social, economic and environmental value) from Information Management. Specifically, a value-driven process model is required.

7 Concluding Remarks

Over its five workshop activities, Network FOuNTAIN established six capabilities that will be important in Digital Built Britain in the coming years. These can be summarised as:

- Capability 0: Capability to gauge Information Management maturity.
- Capability 1a: Capability to establish the appropriate scope of standardisation.
- Capability 1b: Capability to design or extend existing *ontologies in general*.
- Capability 2: Capability to develop current classification systems, schema and frameworks, Uniclass-2015 *in particular*.
- Capability 3: Capability to develop Information Management software.
- Capability 4: Capability systematically to identify and derive business value from Information Management.

Those capabilities are summarised in Appendix F, along with the research required to deliver them. In addition to those capabilities, it is clear that a broader upskilling will be required across the sector, highlighting dependency to the CDBB Pedagogy and Upskilling Network. Of the Network FOuNTAIN capabilities, perhaps Capabilities 1b, 2 and 3 are the most practical and realisable in the short term. Academic groups led by Barr (Newcastle) and Beach (Cardiff) are well placed to tackle the ontological issues of Capabilities 1b and 2. Groups such as the 3DIR and

Information Resilience teams at Loughborough (Demian, Yeomans, Blay, with their experience in built environment IM software prototyping and modelling) are well equipped to tackle the research needed for Capability 3.

These Capabilities are of high priority. Capability 0 can potentially enable and Capability 4 can potentially drive the other Capabilities. Capability 0 aligns with aspects of BS19650 (ISO 2018a,b) and would benefit from collaboration with groups who established that standard and groups who continue to develop it and related standards, such as ISO/TC59 “Buildings and civil engineering works”, ISO/SC13 “Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)”, or ISO/TF02 “Technical Roadmap work proceeding”. Capability 4 aligns with the GEMINI Principles driving the creation of a National Digital Twin (CDBB 2018), and that group within the CDBB can be engaged to deliver Capability 4 and the underlying research.

Capability 1a is the one possibly entailing some more basic research, and is positioned as a longer term target, although it is of fundamental priority.

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APPENDIX A: Workshop 0 Report: Scoping Workshop

Introduction to Information Management

Members and friends of Network FOuNTAIN met on 16 August 2018 in the Loughborough University London campus. The workshop was led by Matthew West of Information Junction. Matthew presented an introduction to the topic of Network FOuNTAIN: "Managing Information in a Digital Built Britain". The presentation covered the following themes:

1. **Data and information quality management**. The value of information comes from its use in supporting decisions. Information Management is about ensuring that the right information is delivered at the right time to the right people. Quality means meeting requirements agreed between information users and suppliers.
2. **Information quality management systems**. ISO9001 applies to information just as it applies to any other product or service. To be successful, a similar approach to managing money is required. This means amongst other things that everyone should know their responsibilities for information and should have tasks and targets set. Information Management is a line responsibility, not an IT responsibility.
3. **An Information Management Landscape (IML) for Digital Built Britain**. Operation of an Information Management process itself requires information and proper administration. The Information Management Landscape (Figure 1) identifies the critical information for successful management of information.
4. **Information Management maturity and how to achieve it** (followed by discussion). IM Maturity can be broken down into five stages: *Initial*, *Recognising*, *Specifying*, *Managing* and *Optimising*.
   - The *Initial* stage is characterised by unconscious incompetence.
   - The *Recognising* stage is characterised by developing plans to develop the Information Management Landscape.
   - The *Specifying* stage is characterised by creating the Information Management Landscape and using it.
   - The *Managing* stage is characterised by measuring your Information Management performance.
   - The *Optimising* stage is characterised by continuous improvement of Information Management processes.
5. **Process models for identifying information requirements**. Process models provide a systematic way to identify information requirements. They need to be developed down to a level where decisions can be identified, along with the information requirements for those decisions. To create the process model, identify the core processes, and then the lifecycle processes of things

required to support the processes. There will be some common processes, such as HR, and finally a procurement process.

6. **Risk management in IM.** The risk of poor decisions can be the result of poor quality information. A standard risk management approach can be taken to assess the costs of poor quality information and thus the benefits of Information Management.
7. **Performance management and KPIs in IM**. Part of your information requirements come from KPIs used to manage the business. Each process and sub process should have a KPI for effectiveness and efficiency.
8. **Data integration**. Effective data integration requires a common language and common structure for information in a data model and reference data (or mappings between standards).
9. **Data modelling for data integration**. A data model for data integration needs to be extensible. This can be achieved by the data model being a model of "life the universe and everything". This requires in turn a good understanding of ontology.
10. **Reference data libraries**. Reference data libraries are the way an integration data model is extended to cover particular domains. Great care needs to be taken when doing this. Mistakes are easy to make.

Discussion: Information Management Maturity

After item 4 above, a discussion session was held in which the cohort split into three groups and each group discussed the current state of Information Management maturity in the industry as-a-whole as well as in individual organisations. The following ideas emerged, as recorded in flipchart sheets:

- Maturity of whole industry
    - Shift from "outputs" to "outcomes" also applied to IM.
    - The industry-as-a-whole is at *Recognising* maturity. Some felt that parts of the industry were still at the *Initial* stage. There is varying maturity across different departments.
    - At the publication of the Latham Report in 1993, it was still at the *Initial* stage. The Avanti case study in 2007 signalled *Recognising* maturity.
    - COBie is an important milestone in IM maturity, as is the concept of Open BIM.
    - Risk, responsibility for information and other legal issues are barriers to IM maturity.
    - There is general resistance to change, and partners in a fragmented industry each want to do things their way.
- Maturity of individual organisations
    - The client is the most important "organisation" to drive maturity, pushing the IM agenda or pulling the information it needs.

Discussion: Current Research mapped to Information Management Landscape (IML)

After item 10 above, the workshop closed with a discussion session in which attendees were asked to map their current research to the Information Management Landscape presented earlier in the day (Figure 1).

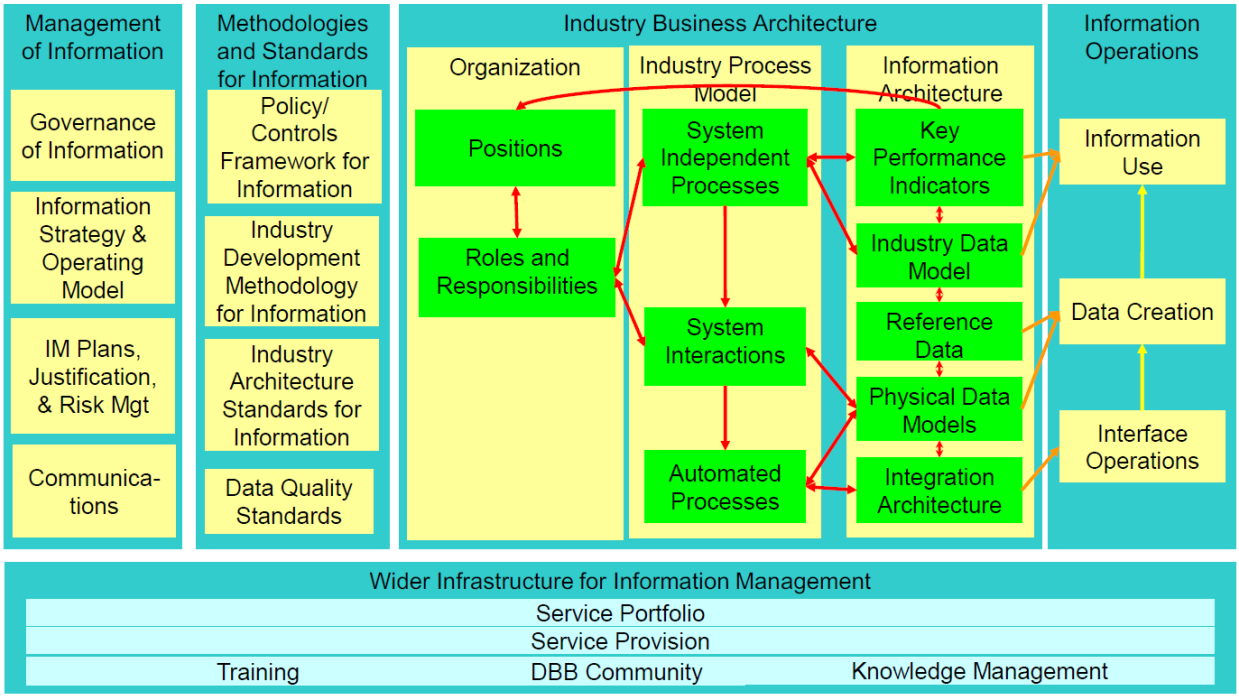

Figure 2: The Information Management Landscape from "Towards a Digital Built Britain: Introducing the Information Management Landscape." Draft White Paper 2018 by Matthew West & Alastair Cook.

The table below lists various elements of the IML (with the numbering in the left - hand column conveying the nested nature of those elements) and the attendees who felt they conduct research linked to that element. Attendee initials were replaced by a letter code to observe the Chatham House Rule, whereby information discussed during the workshop would be shared but not attributed to any individual attendee. This should continue to facilitate an open discussion in future workshops. When considering the mappings in the table below, the nested nature of the IML items should be kept in mind; research in a higher IML level item might imply that this research activity can also be mapped to that item's subtree items.

		A	B	C	D	E	F	G	H	I
1	Management of Information									
1.1	Governance of Information			X	X					
1.2	Information Strategy & Operating Model				X	X				
1.3	IM Plans, Justification, & Risk Management									
1.4	Communications									
2	Methodologies and Standards for Information	X	X				X			
2.1	Policy/ Controls Framework for Information									
2.2	Industry Development Methodology for Information									
2.3	Industry Architecture Standards for Information									
2.4	Data Quality Standards	X					X			
3	Industry Business Architecture									
3.1	Organization			X						
3.1.1	Positions									
3.1.2	Roles and Responsibilities				X				X	
3.2	Industry Process Model			X						
3.2.1	System Independent Processes						X			
3.2.2	System Interactions				X			X		
3.2.3	Automated Processes								X	X
3.3	Information Architecture									
3.3.1	Key Performance Indicators									
3.3.2	Industry Data Model	X			X	X	X		X	X
3.3.3	Reference Data	X			X				X	X
3.3.4	Physical Data Models									
3.3.5	Integration Architecture									
4	Information Operations							X	X	
4.1	Information Use							X	X	
4.2	Data Creation					X				
4.3	Interface Operations									X

Figure 3: Table of research conducted by attendees, mapped to Information Management Landscape.

Elements of the IML with no research at all listed as being conducted by workshop attendees:

- 1-Management of the Information Management Landscape
- 1.3-IM Plans, Justification, & Risk Management
- 1.4-Communications
- 2.1-Policy/ Controls Framework for Information
- 2.2-Industry Development Methodology for Information
- 2.3-Industry Architecture Standards for Information
- 3-Industry Business Architecture
- 3.1.1-Positions
- 3.3-nformation Architecture
- 3.3.1-Key Performance Indicators
- 3.3.4-Physical Data Models
- 3.3.5-Integration Architecture

APPENDIX B: Workshop 1 Report: Ontologies

Workshop Proceedings

Members and friends of Network FOuNTAIN met on 14 September2018 in the Loughborough University London campus. The workshop was led by Professor Stuart Barr of Newcastle University and Dr Tom Beach from Cardiff University. Tom presented an "Ontology Tutorial", and then several participants presented case studies of how ontologies were used in their professional practice.

These presentations were followed by a discussion of the current industrial/academic use of ontologies, gaps in the state-of-the-art and opportunities for future development.

Ontologies Fundamentals

- Ontologies have objects and relationships.
- The term "Embankment Problem" emerged from one of the case studies to describe the common occurrence of different people having different ways of representing the same thing. Different representations can be appropriate for different purposes. The definition of the property of an entity might depend on the person interrogating the model.
- A common language is difficult to establish, but when established is extremely valuable. This was identified as one of the main challenges. Simple to achieve technically but achieving consensus is difficult.
- To what extent should the ontology be standardised/fixed or flexible? The balance between standardisation and extensibility was discussed at length. A balanced approach is to standardise common aspects and allow users to extend bespoke aspects. Too little standardisation means high flexibility but can result in the "Embankment Problem". Too much standardisation means inflexibility and risks people not using the ontology. The balance can be expressed in terms of "standardising the right things", rather than too much or too little standardisation. In short, achieving good standardisation enables innovation – rather than restricts it.
- "Four-dimensionality" was proposed as an interesting theoretical approach. For the question: *How many cars are there?*, in a three-dimensional view, we ask the satellite to take a picture and we count the number of cars. However, in a four-dimensional view, the answer is for a particular time or a point in the dataset. Today's answer might not be valid tomorrow.
- Existing frameworks specify the structure of data. Uniclass-2015 catalogues a set of different "drawers" in which objects can be placed. However, it lacks the flexibility semantically to describe objects. For example, the draining of the air conditioning unit can be categorised as a mechanical system. However, one might need that pipe to be categorised as a draining system as well.

- Ontologies/frameworks also provide the scope for manufacturers to contribute with libraries of classes or individual objects. On large complex projects, for creating Asset Information Requirements, we should consider Asset Data Dictionary (ADD) which is populated by Asset Data Definition Dictionary Documents (AD4s), each one telling those working on the project, what information they are expected to generate, what form it comes in and when they need deliver it. Also to be considered are the created outputs called Product Data Sheets (PDSs), which are derived from completed Product Data Templates (PDTs).

Questions for the design of ontologies:

During discussions, members formulated some questions related to the design of ontologies for DBB:

- The ontologies framework is required to be a high-level definition, then anything can fit. How do you start from the top?
- The framework allows for a coordinated dataset in which multiple stakeholders input data. What are the security dimensions of the data? For example, who inputs equipment's warranty: the designer, the contractor, or the supplier?
- What is the scope of the framework? For example, is it Digital Built Britain or Digital Living Britain (delivery of the Built Environment and the services that depend on it: education, health, transport)?
- Ontologies as a standard constitute a public good so should they not be centrally funded?
- A member of the network stated that the methodology to design the ontologies for DBB can be formulated now. However, the standard will require continuous maintenance. The maintenance should be funded by the statutory bodies at the city scale.

Wrap-up questions:

During the final stage of the workshop, the network summarised the discussion with the following questions:

- Some "principles" need to be established at the outset, before designing or adopting an ontology. What are the needs and purposes of information creators, managers, users?
- Define top level ontological concepts – building on an appropriate framework 4D or 3D, this decision should be made early on.
- Top level ontology should be extensible based on a set of defined rules.
- Consideration should be given to security management.
- What are the strengths and weaknesses of existing frameworks/ontologies (IFC, Uniclass-2015, CityGML, COBie)? Where do gaps exist? Can we define core problem areas with real world examples to drive their adoption?
- What is the scope: buildings, cities, infrastructure, linear infrastructure?

- How can we make ontologies work in companies?
- How do you mix data and files?
- What can we learn from other industries?
- How do we assure quality/validation of data?
- How do we assure the custody of data?
- What is beyond the Digital Twin?
- How to standardise existing asset management systems?

Next steps:

- Define the pillars of the ontology framework for CDBB (including candidate top level of ontologies)
- Establish appropriate design principles for new ontologies to be created.
- Integration of the work of Network FOuNTAIN with other networks and projects, e.g. “D-COM: Digitisation of Requirements, Regulations and Compliance Checking Processes in the Built Environment”
- Define current capabilities and future capabilities
  Categorise existing relevant ontologies – strength and weaknesses of different ontologies that currently exist in the area.
- Identify elements of IFC (or related use cases in other domains) and test mapping
- Ensure coverage is wider that building infrastructure /natural environment/ CITYGML Utility Infrastructure Network

APPENDIX C: Workshop 2 Report: Ontologies for Cataloguing Information

The Aim

The original aim of Workshop 2 was to focus on creating a list (or catalogue) of all of the various types of information that require managing in a Digital Built Britain. However, following a number of informative discussions with various participants in Workshop 0 (Scoping) and Workshop 1 (Data and Ontologies), it became apparent that simply listing already existing standards and ontologies used within professional practice, and attempting to generate such a list from a synchronous workshop setting might be akin to "reinventing the wheel". As an alternative, members suggested that a more productive approach would be to engage a panel of expert practitioners (available within the Network) to review current ontologies and standards, to investigate how they categorise information. Consequently, the workshop was replaced with a revised methodology aimed at conducting an expert survey to facilitate acquisition of the inherent knowledge and expertise amongst members of the network. This new approach also incorporated use of the Delphi method through an online platform Mesydel, which was chosen to expediate the process of data collection and synthesis given a limited time frame. It was acknowledged from the outset that the new scope of this work had to be scaled down to reflect the time available and ensure it did not reach too far beyond the scope of the original proposal. The revised aim of this particular activity was "to Investigate ontology approaches within a Digital Built Britain." The objectives were:

1. To determine the strengths and weaknesses of current ontologies for Information Management in the construction industry.
2. To catalogue of the types of information which need to be managed in Digital Built Britain.
3. To identify the project process that aligns better with Information Management in Digital Built Britain.

Adopted Approach

An initial desktop literature review was conducted to identify current ontologies for Information Management in the built environment, a catalogue of information types, and a list of project processes within the current standards. The Delphi method was then applied in an attempt to achieve a reliable consensus from the panel of experts over two initial rounds of enquiry. A third round was included to capture additional comments from the experts, as well as substantiate experts' key credentials. Upon the conclusion of round one, survey facilitators provided an anonymous summary of the experts' input, which was then used to inform consensus building in the subsequent round. Participants were encouraged to review the anonymous opinions of all experts, before being provided with an opportunity to revise their previous response, thus supporting a more consensus-based conclusion.

The resulting questionnaire contained four key sections:

Section 1: enquired about the suitability, completeness, and adaptability of current ontologies i.e. Industry Foundation Class (IFC); Uniclass-2015; Construction Operations Building Information Exchange (COBie); CI/SfB; and City Geography Markup Language (CityGML). Questions were assessed using a Likert Scale from 1 to 5.

Section 2: interrogated participants about the possibility of combining ontologies to obtain a more comprehensive information catalogue, as well as current and future trends that need to be addressed in Digital Built Britain.

Section 3: asked the experts to define what are the most important types of information, through use of the classification taken from Uniclass-2015. Open-ended questions were then used to explore current and future trends in types of information.

Section 4: enquired about the suitability, completeness, and adaptability of current process models, namely, Construction Industry Council (CIC) Scope of Services, RIBA Plan of Work 2013, PAS1192:2 and the Government Soft Landings. Again, a Likert Scale from 1 to 5 was applied.

A pilot questionnaire was sent out on 11 October 2018 to two voluntary members of the Network. Feedback ascertained from the pilot helped to identify the need to include the following key question. “To what extent would the ontology approaches for a Digital Built Britain help achieve the DBB's mission?” This relates to the digital transformation of the full lifecycle of the built environment to increase productivity and improve economic and social outcomes in the UK.

A total of 17 out of 39 Network members (participants) were initially identified as appropriate to contribute to the survey (based on their role as construction practitioners. The main criteria for the initial sample stemmed from potential participants having 1) an industrial position, and 2) knowledge and / or expertise in ontology-based Information Management.

The first survey round was issued on 22 October and respondents provide with two weeks to complete the questionnaire. The quantitative responses (based on the Likert scale) were analysed using mean and the median, whilst qualitative responses were analysed to inform changes required for round two. Therefore, in sections 1 and 4, the mean and median of each response was calculated. In section 2, the most voted combinations of ontologies were ranked from top to bottom according to the collective preference. In section 3, the most voted information types were ranked from top to bottom according to the collective preference. Additionally, new information types were identified as current a and future trends and then fed into round two.

A second questionnaire was issued on 16 November, with eight of the nine experts replying to the second-round survey (one participant chose not to participate further

during this stage). This time, sections 1 and 4 asked if experts would like to reconsider their responses in light of the provided aggregated responses from round one. Section 2 asked the experts to assess if they agree or disagree with the proposed combinations of ontologies suggested by others in round one (1=Totally Disagree and 5=Totally Agree). Finally, in section 3, experts were asked to assess the importance of information types for Digital Built Britain (with responses assessed from 1 to 5 (1=Unimportant, 5=Very important).

As no significant change between round 1 and 2 were found in the overall responses (mean or median) to questions in sections 1 and 4, it was decided not to conduct a third round. Additionally, some experts indicated that section 2 would be better reframed as a catalogue of 'dimensions' or 'subject areas' that need to be combined in order to develop a more comprehensive ontology; rather than a combination of existing ontologies. For this reason, a final third round questionnaire will be sent to the eight experts on 18 December, asking them to define the 'dimensions' or 'subject areas' of an ontology approach for a DBB (e.g. geometry, building material, cost, etc.). This final round will also provide opportunity for further comments to support previous responses in rounds 1 and 2.

Initial Findings

Experts could not reach full consensus on one particular ontology being the most suitable for a DBB. This is based on none achieving a required score between 4 and 5 to be classed as a consensus, and with a standard deviation as a tenth of the scale (SD=0.50) for suitability, completeness, and adaptability. However, Uniclass-2015 did score the most highly, with an overall marks for suitability of 3.75 (SD=0.97) and adaptability at 3.71 (SD=1.16).

None of the existing project processes reached the required average either (range between 4 and 5) and with a standard deviation as a tenth of the scale (SD=0.50) for suitability, completeness, and adaptability. However, the project processes of PAS1192:2 scored the most highly. Its overall rank for suitability achieved a score of 3.88 (SD=0.93) and adaptability was 3.57 (SD=0.90).

Finally, Table 1 below provides detail of the experts' opinion on what are the most important information types to support a DBB (that is those types that score higher than 3). It is also acknowledged that there remains a need to catalogue the 'subject areas' for a comprehensive ontology for a DBB.

Table 1: The most important information types for a Digital Built Britain (in ranked order)

Rank	Information Type	Mean	Standard Deviation
1	Asset information (maintenance, operations, performance)	4.50	0.50
2	Datasets (GIS dataset, information exchange file, room data sheet)	4.00	1.00
3	Record Information (certificate, forms, manual, plan, register, report)	4.00	0.71
4	Graphical (drawing, 2D models, 3D models, photograph)	3.63	1.11
5	Big data (performance)	3.50	0.71
6	Design information (calculation, schedule, specification)	3.50	0.87
7	Contractual (contract, instruction)	3.38	0.70
8	Financial (bills of quantity, cost plan, invoice)	3.00	0.71

As a final third round questionnaire will be released in late December (as we write this report), further analysis will be required before the full context of the findings can be ascertained. The conclusions of this work are expected to be completed by end of January 2019 and will be reported back to the CDBB accordingly. It is anticipated the final outputs will also be released in the form of a journal paper by early summer 2019.

APPENDIX D: Workshop 3 Report: System Requirements

Workshop Proceedings

Members and friends of Network FOuNTAIN met on 26 October 2018 in Loughborough University. The workshop was led by Dr Peter Demian. The following presentations were given:

- BIMs, CDEs and three modes of interacting with information (Dr Peter Demian)
1. Search & Retrieval (Dr Peter Demian)
2. Browsing & Exploration (Dr Peter Demian)
3. Information Delivery (Dr Peter Demian)
- Information Scientist's Perspective (Ginny Franklin, Loughborough University Academic Librarian to the School of Architecture, Building and Civil Engineering)
- CDE Perspective (Aysar Abou Kheir, Senior Consultant, Asite)

Each of the three main presentations was followed by a discussion of the current industrial/academic views on that mode of interacting with information, gaps in the state-of-the-art and opportunities for future development.

BIMs, CDEs and three modes of interacting with information

The purpose of this workshop was to explore the software requirements in Building Information Modelling (BIM) and Common Data Environment (CDE) platforms, focusing on the *consumption* (as opposed to the *production*) of information. The balance of labour between production and consumption was noted. The more effort one puts into the production side (by indexing, categorising, using file naming conventions), the easier it is (subsequently) to find and consume information. Conversely, in repositories where information is not carefully indexed, organised into folder structures, or where files do not follow a naming convention, it might be harder to find, understand or use information.

Three modes of interaction were presented:

- Search and Retrieval
- Browsing and Exploration
- Information Delivery

The choice between the three modes depends on the task at hand, the type of content (information) being managed and (most importantly) the user's awareness of his or her information need. If the user knows exactly what information is needed, he/she will be able to articulate a query, search and retrieve the required information. If the user is unsure exactly what information is needed, but has some notion of an information need, browsing and exploration

might be more appropriate. If the user has no idea what information is needed, or is even unaware that there is a need for information or that useful content might be available, the system unilaterally *delivering* information to the user might be the most effective mode of interaction.

With the digital transformation of construction, and increasing content uploaded to CDES or crammed into BIMs, the aim of the workshop was to establish the required software functionality in these platforms for consuming that information.

Mode 1: Search and Retrieval

Search and Retrieval is appropriate when the user is aware of the information need with some precision, and the nature and sheer scale of the information make it difficult to visualise the whole repository and explore it systematically. The three classic steps in the information retrieval process are:

1. Formulate a query
2. Identify relevant information (form an index)
3. Present search results

Peter presented the example of the 3DIR project, which addressed the situation where information was linked to a 3D artefact, and proposed mechanisms for formulating queries, identifying relevant information and displaying search results, exploiting that 3D link (Demian *et al.* 2016).

The ensuing discussion was structured around the three steps of formulating queries, identifying relevant items, and presenting search results. The following points were raised:

Formulate a query

- Keyword queries remain the most important mechanism.
- Queries in a natural language would be extremely useful from the perspective of the non-technical end-user. This is particularly true for clients.
- Query templates would help non-technical users.
- Queries based on visual programming need to be explored, compared to visual programming where inputs and outputs of functions are visually represented.

Identify relevant information

- The issue of information overload was noted; there might be too many “relevant” items, and ranking was important.
- The balance of labour was noted in identifying relevant information between the system and the human user. To what extent should the system “tell you” what is relevant, vs. the use of tags or other indicators left by the creator and previous users of the information?

Present search results

- It is important that search and retrieval systems should observe information access protocols and restrictions.
- A text listing of search results will always be useful.
- Search results can be superimposed on the 3D model.
- There might be interesting applications of Virtual Reality and Augmented Reality.

General points

- Context is generally important, and is a particular challenge in Search and Retrieval.
- Search systems needed to be able to span various systems and repositories. With the "federated model" in mind or "federated twins", it might be some time before all the information to be searched was in one location. Open standards are required.
- Search and Retrieval will depend heavily on different project phases. Design, construction and operation will differ significantly in the functionality needed.
- The scale is important. Different "lenses" will be required for *buildings* and for *cities*.
- The concept of *digital twins* was discussed. The concept was questioned and it was suggested that it might be too general. What information should constitute the digital twin: tender model, design model, operation model? What is the information suitable for, who is it suitable for? What information should be included in the digital twin? (For instance, information from design reviews?)
- With the sheer quantity of information, the time required to process queries might also be an issue.

Mode 2: Browsing and Exploration

Browsing and Exploration is useful when the awareness of the information need is not precise enough to enable formulation of an explicit query. It might also be more effective when interacting with a moderately sized (rather than large) repository of information. Even though no explicit query is formulated, some data from the user's current task can be extracted and used as *an implicit query*, to highlight potentially relevant items in the repository. The "Shneiderman mantra" of "overview first, zoom and filter, and then details on demand" was cited (Shneiderman 1996). Peter presented the CoMem project as an example of this mode of interaction (Fruchter and Demian 2002).

The following points we raised in the discussion:

- Uniclass-2015 emerged as the most likely candidate framework for Browsing and Exploration, based on the experience of workshop attendees. Other frameworks should also be considered if other lenses are needed.
- The relative simplicity and hierarchical nature of Uniclass-2015 are both beneficial characteristics.

- The attendees questioned whether Uniclass-2015 is useful for the lifecycle of Digital Twins?
- The limitation of Uniclass-2015 is that some products pertain to multiple systems, i.e. may need be classified in different ways at the same time.
- It can be argued that earlier versions of Uniclass are comprehensive for buildings but not for infrastructure, although this can be contested for Uniclass-2015.
- In addition to Uniclass-2015, it was concluded that Browsing and Exploration could be structured according to project process breakdowns, or according to Work Breakdown Structure models.

Mode 3: Information Delivery

If the user has no idea what information is needed, or is even unaware that there is a need for information or that useful content might be available, the system can unilaterally *deliver* information which might be deemed relevant based on an implicit query from the user's current work.

Peter presented the example of the Office Assistant which was included in Microsoft Office for Windows (versions 97 to 2003). This often took the form of a paperclip that detected when the user was (for example) writing a letter and offered help. It was considered disruptive and ineffective, and is often considered as a striking failure in human-computer interface design. This mode of Information Delivery was therefore presented with caution. However, it was noted that work protocols in DBB did require that information be delivered to particular stakeholders at particular times (for example, CDE Sub Group 2018).

- Attendees concluded that this mode of interaction will sometimes be appropriate in Digital Built Britain and was not always disruptive. Machine learning can be used to improve delivery of relevant content over time.
- An example of a useful application of Information Delivery can be reminders for asset management (e.g., when lightbulbs need to be replaced).
- An interesting application domain might be the European Programme for Critical Infrastructure Protection.

Information Scientist's Perspective

Ginny Franklin, University Librarian, gave a presentation covering the history of information retrieval. Her presentation overfed the following points:

- Building up a complex search in a stepwise fashion.
- Choosing appropriate keywords via a thesaurus.
- Limiting to a particular *treatment* (the way a particular search term is used).
- Browsing.
- Graphical ways to explore results.
- Saving searches and set up alerts.

The discussion following Ginny's presentation focused on the issue of *quality*, and how attributes such as level of sharing could be explicitly tagged or implicitly inferred when searching.

CDE Perspective

At the close of the workshop, Aysar Abou Kheir gave a comprehensive demonstration of the Asite platform in light of the discussions of the day.

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APPENDIX E: Workshop 4 Report: Business Models

Workshop Proceedings

Members and friends of Network FOuNTAIN met on 30 November 2018 in Loughborough University London campus. The workshop was led by Dr Mohamad Kassem from Northumbria University. The agenda was structured as follows:

1. New business models exploiting digital data under DBB
2. Specific Drivers
3. Breakout Session 1 – Use Cases: delivering value leveraging digital data under DBB
4. Breakout Session 2 – Exploring business models for selected Use Cases
5. An ontology for DBB Business Models?
6. Wrap-up

New business models exploiting digital data under DBB

The main points presented by Mohamad were:

- Objective of the session: To establish the need for business models that unlock value for digital data in DBB.
- There is a need for a systematic way to review business models from a value standpoint.
- Construction is currently driven by a focus on capital expenditure. However, Digital Built Britain requires a lifecycle perspective (whether lifecycle of the built asset or of the digital content about the built asset). This has radical implications on Information Management and in particular on how the Information Management processes could unlock value.

Specific Drivers

Specific drivers were presented by Mohamad for defining business models:

- Value innovation: users/occupants/communities can create value systems based on what they deem important. There is an increased emphasis on sharing resources and services. Communities and supply chains are empowered and enjoy increased control and influence on creating business logic and productive processes.
- The increased volume of data and the improved conversion: of *data* into *information*, *knowledge* and *wisdom* are both important drivers for business models.
- Connectivity technologies (Internet of Things, sensing, smart cities, connected workers with mobile devices). The improved connectivity of professionals and devices enabled unprecedented information flows and offers a plethora of opportunities to unlock the value of digital data.
- Customisation: off-site production potentially streamlines the construction process but gives rise to the need for customisation. The example was cited

of the "Off-site manufacture for construction" report of the House of Lords Science and Technology Committee, which highlights the value of data gathered using sensors embedded in building components.

Breakout Session 1: Value

The following points were made by attendees in the subsequent discussion:

- Waste might be the "low-hanging fruit" in delivering value from Information Management. An example of waste is unused capital equipment during the construction stage. Managing information might eliminate this waste by enabling shared use of equipment. Value comes from eliminating waste but *value* and *waste* should not be limited to *financial value* and *financial waste*. The cost of eliminating the waste should be less than the cost of the waste.
- Deriving value from digital information might be enabled by innovation. I innovation in construction is often characterised by hype with no substance. Innovation is easy, but success is difficult.
- Value must be considered holistically, from a systems perspective. What is the value of driverless cars? Considered in isolation, driverless or electric cars might seem clearly beneficial to society (less energy consumption, less CO_2 emissions, reduced need for parking, etc.). However, once the costs of generating alternative energy is considered, they might not seem so beneficial. Value from Information Management and innovations exploiting new digital data and information should consider a whole systems perspective. This could have a positive impact on the acceptance of new Information Management practices.
- The vast volumes of building models and information uploaded to CDEs offers an opportunity for machine learning. The group discussed the ethics of using data from CDEs in this way.
    - It is unethical (and illegal) without the consent of the owners of this information, and such consent would be difficult to secure.
    - There might be a clause in the licence agreement which allows the provider of the software service to perform analytics on the data. There should be
    - There might be an incentive for the owners of the data to allow it to be used for analytics in this way (to derive value); the end users might benefit from the findings of the analytics.
- As a conclusion from this item/example, value generation can be challenged by legal / IP aspects. The regulatory framework will have an increasing influence on value generation in Digital Built Britain.
- The tension between *production* and *consumption* of information was discussed. Benefits came mostly from consumption, but consumption was impossible without production. The issue of duplication of work was noted: various reports have noted the wasted resources in producing information that

already existed elsewhere. Hence, to unlock value under DBB, information production may need to be incentivised.

- Information is usually produced by designers and consumed by constructors. Complications and trust issues arrive because there is often no direct contractual relationship between the two parties. Designers produce a design intent model which might be unsuitable for construction. Contractors might need to remodel portions of the design. Information Management in DBB should address the "value to whom" dilemma.
- The construction-operation disconnect is even more wasteful than the design-construction one. This interface is critical to unlock value from Information Management in DBB.
- A discussion was had about whether developments such as machine learning and artificial intelligence add value? Some jobs are taken away. Should we be worried? New jobs appear; upskilling becomes the issue. Social value should be considered.
- In identifying use cases, a four-quadrant grid was used to map value (low – high) against the likelihood (high or low) of the use case. It is already used by others (e.g. ICE) to map innovation in construction, and offsite construction is one of the practices/innovation considered to have high-likelihood and high-value/impact.

Breakout Session 2: Use Cases

- Mohamad used the standard business Canvas model to focus the discussion.
    - Key partners
    - Key activities
    - Key resources
    - Value preposition
    - Customer relationships
    - Channels
    - Customer
- The question was posed: How can digital data help to achieve business value (including economic, environmental, and social value)? Two case studies were chosen. The discussion focussed on four items from the business canvas: Key Partners, Key Resources, Value Proposition and Customer Segments.
- Use Case 1: Measurement of productivity in provision of services in hospitals
    - The problem: measurement of services is not made at all.
    - Key partners: customer, end-user, regulators, healthcare providers, equipment suppliers, operators, investors, data providers, society, community, politicians.
    - Key resources: access to facility management information, people, equipment.
    - Value preposition: throughput and occupant experience.

    - Value preposition for dental practices: ability to transfer information of patients between practices.
    - A discussion was had of who is the end user: the investor or the occupant (patients, staff, operators). Thus, who benefits from the digital information. Hence, the question "value to whom" is important.
    - The contrast was noted between Value for the performance of the buildings vs. Value for the users of the facility.
    - Better quality of data > Make better decisions > Better throughput
- Use Case 2: Shared use of capital equipment (contractor's point of view)
    - Value preposition: improve equipment utilisation on site to reduce the cost per project.
    - Driver – connectivity: Use of sensors in equipment. The user can see in a dashboard real-time information about items of equipment and allocate them to different projects in order to improve utilisation.

An ontology for DBB Business Models

An architecture (ontology) was presented which can be used to express business value.

Wrap-up

Retaining the focus on *delivering business value from Information Management*, attendees discussed the merits of ontologies, business models, process models.

In the losing discussion, workshop attendees concluded that:

- The information ontology for DBB needs to be agreed first [this is part of the output of Workshop 2 from Network FOuNTAIN]. This should be a universal language that satisfies everyone. This ontology must demonstrate jhow Information Management delivers business value.
- As a first step, a pilot project needs to be implemented: piloting means to be successful in terms of delivering value from Information Management. The pilot can implement the ontology and then analyse the value of the information.
- In the longer term, it would be useful to design a *process model* (rather than an ontology) to deliver business value.

APPENDIX F: Capabilities and Research Matrix

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Capabilities and Research Matrix

Capability	Rationale and Drivers	Timescale to realise	Enabling Technologies and Behaviours	Barriers to development or adoption	Supports and Case Studies	Suggested Research Needs
Capability 0: Capability to gauge Information Management maturity, as part of existing standards or new standards.	IM is a crucial aspect of DBB. A capability cannot be managed or improved without the ability to measure is maturity or performance.	Medium	Existing standards (such as the PAS 1192 framework) can be reviewed and modified, and (if necessary) new standards developed to enable stakeholders to gauge their Information Management maturity. Both research and initiative are needed.	There is a plethora of standards already applicable in Digital Built Britain.	Secondary data might exist from stakeholders outside of the construction sector, but a range of construction projects and stakeholders is needed.	A review of existing DBB standards is needed, as well as primary data collection about the specific IM practices of DBB stakeholders. His can be combined with concepts from management science literature to refine existing standards or develop new ones.
Capability 1a: Capability to establish the appropriate scope, priorities and pace of standardisation.	Ontologies are crucial for interoperability and IM iin a DBB. However, ontologies pose a challenge in that their one, standard laguage for describing the world is rarely universally shared by a diverse set of stakeholders. The ability to discern *what* and *how much* to stanardise is crucial.	Long	Research is needed to establish fundamental first principles what can be applied at industry, project and organisation levels.	The diversity of stakeholders at the industry level might make it difficult to establish common principles.	The CDBB, BRE and BSI are important stakeholders to be engaged.	Research is needed to establish a set of principles which can be invoked to establish the appropriate extent of standardisation for projects, organisations or the whole industry.
Capability 1b: Capability to underpin data exchange and integration by developing an appropriate approach to develop new, to extend and adapt existing ontologies, and to create the means to integrate current schema and classifications.	Despite their crucial role, most professionals will lack the practical expertise to adopt/extend or create ontologies.	Short	Repositories of ontologies exist, and it would not take much research to formulate a guide of using those as part of professional practice in DBB. Initiative is needed is needed to establish such a guide in professional practice.	The plethora of guides already available might down out this additional guidance.	Support is needed from software developers and standards authorities/	Best practice from construction stakeholders needs to be collated, along with consultation with oncology experts.
Capability 2: Capability to develop current classification systems, schema and frameworks, Uniclass 2015 in particular, to maximise the potential to share data, in ways that make best use of current skills and investments.	Same as for Capability 1b, but specific to Uniclass	Short	Same as for Capability 1b, but specific to Uniclass	Same as for Capability 1b, but specific to Uniclass	Same as for Capability 1b, but specific to Uniclass	Same as for Capability 1b, but specific to Uniclass
Capability 3: The capability to develop fit-for-purpose software which enables stakeholders •to query information repositories visually or using natural language •to explore information repositories based on current models (such as Uniclass-2015) •to interrogate information repositories automatically using ontology-based tools, and •to set information delivery schedules based on industry and project protocols,	DBB stakeholders have particular types of information needs, which regularly evolve in response to the changing DBB landscape.	Short	More research is needed to confirm software requirements and initiative is needed from CDE and BIM platforms.	Needs are constantly changing.	Support is needed from BIM and CDE developers.	More research is needed on the human-computer interface design and information retrieval computations from BIM and CDE tools.
Capability 4: The capability to identify and derive business value from Information Management. (A prescriptive process model is needed.)	IM offers an important business opportunity, but will not be exploited unless the business value can e measured and realised.	Medium	Research is needed to apply business process modelling to articulate the business value of IM and formulate a business model for its realisation.	Organisations are already under pressure to measure many aspects of performance.	Construction project/stakeholder case studies are needed.	Research is needed into the business value of IM, and the formulation of a business process model.