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Investigating innovative communication processes within construction domain by using structured information exchange

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Contents

Table of Figures

Abbreviations

BIM - Building Information Modeling

CDE - Common Data Environment

IDM - Information Delivery Manual

MVD - Model View Definition

BPMN - Business Process Model and Notation

LOD/LOMD - Level of Development or Level of Model Definition

bSDD - buildingSMART Data Dictionary

IFC - Industry Foundation Classes

OWL - Ontology Web language

COBie - Construction Operations Building Information Exchange

CAFM - Computer Aided Facility Management

XML - Extensible Markup Language

W3C - World Wide Web Consortium

URI - Uniform Resource Identifiers

URL - Uniform Resource Locator

RDF - Resource Description Framework

RDFS - Resource Description Framework Schema

DL - Description Framework

SQL - Standard Query Language

RIF – Rule Interchange Format

SWRL - Semantic Web Rule Language

LOD/LD - Linked Open Data

SME – Small and Medium Enterprises/Businesses

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EE3, Master's Thesis Project

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Executive summary

Master's Thesis | In collaboration with Nohara Holdings Inc.

Topic - Investigating innovative communication processes within the construction domain by using structured information exchange.

Tasks - Investigate the methods, level of awareness and adoption of structured way of information exchange and standardization. Identify pain points, needs, and challenges within the construction industry when it comes to implementing standards. Gather expert opinions on current AEC industry status on the level of implementation.

Problem statement – Need to address the issues of interoperability and lack of integration between the AEC stakeholders through standardization. However, challenges in terms of complexity of technologies/ methods, lack of technical knowledge and fragmentation are hindering the pace of adoption. Standardization efforts within Industry are significantly top-down (government mandates on public infrastructure projects, standardization organization (BSI, ISO)), a potential bottom-up approach could aid with increasing the level of awareness and adoption.

Proposed solution – Addressing implementation of standardization as a change process within organizations. Proposing an incremental change process framework for SMEs in the AEC industry to aid the implementation of standards and inculcate innovation within organizations. Multiple frameworks, theoretical models, concepts of innovation management, and methods of implementation and change management were researched and evaluated for the purpose of creating the change process framework that will potentially work with SMEs.

Summary of Framework – Re-structuring SMEs, on evidence-based need to implement changes within the organization. An iterative approach that involves members from all levels within the organization at different stages of the framework, to identify where are the lack of capabilities and potential willingness for reeducation. Defining new tasks and roles on top of existing ones and using the RASCI matrix to have clarity in new defined tasks and roles. Making structured and informed decisions to fulfill the missing capabilities. Evaluating progress based on established key

performance indicators and realigning the course of incremental change based on the feedback and as per business requirement.

Value of proposed solution – The Change process framework proposes agile, future proof, flexible, and iterative ways to identify what are the missing capabilities and what is needed for the organization to implement standards. It is a tool kit for SMEs to use as a reference for implementation of new processes, for identification of missing competencies and resolution proposal to filling them in.

1. Introduction

1.1 Project Abstract

The current world pandemic has certainly influenced the way people and organizations communicate and exchange information. As zoom, MS Teams and skype are dominating the ways of working, organizations across different domains are increasingly facing new challenges in terms of rigidity and efficiency in existing processes of information exchange; especially when it involves a large amount of information with varying sensitivity and multiple stakeholders.

These challenges are deepening the existing need to thrive in drastic changes due to technologies in the last decade that are driving businesses to become agile, to ensure growth through innovation, and strive for enhancing their communication capabilities. For businesses and processes that involve multiple disciplines, such as the construction industry, developing innovative communication processes will potentially be a strategy to become agile and future-proof. This strategy leads to a pressing need for effective cross functional collaboration and interoperability with standardized processes and methods such as structured vocabulary and semantics, to make processes more effective and efficient.

The possible benefits of implementing such innovative processes like effective automation, reducing human error, increasing quality of data, increasing productivity, conflict detection, tracking, and managing changes within projects will potentially provide agility to businesses. On the other hand, there are risks like uncertainty of return on investment, data security, privacy issues, risk of communication error, hindrance in the implementation of IT systems, and resistance to change that makes it challenging for businesses to pursue such a strategy.

Keeping these gains and pains in mind, methods such as linked data, classifications, and graph data models will provide a structured framework for effective information exchange. It will also help overcome the above-mentioned risks and bear the benefits of increased quality of data, filling the gaps for automatic and effective data and process management. This report will be an explorative study that will include investigative research, analysis, and evaluation of methods (1); BIM, linked data, classifications, and modelling data using semantic graphs, and (2); SME's

current level of awareness, adoption, and implementation within the construction industry. The goal is to use the insights from the investigation and create a framework/ direction for implementing of standardization for structured information exchange among stakeholders.

1.2 Methodology

The investigation starts with conducting literature and theoretical research on communication methods as mentioned above. Parallelly, conducting qualitative analysis with use case through collaboration with the company – Nohara holdings and quantitative analysis by gathering corporate examples of if and how such methods are used in practice, talk/interviews with employees/experts. It is followed by investigating whether these methods address the pains and gains and understand the current state of technology adoption, is the adoption fast or slow, and the extent of awareness of these methods in practice, types, and size of organizations. Will it be accessible and adaptable to small and medium-sized companies? Based on the insights from the analysis and interviews, identify the requirements and basic capabilities for establishing the methods within businesses. Assess and evaluate the benefits and ease of implementing the strategies within organizations. Using inspiration from theoretical models and practical examples, plan for implementing it in a business, how to do it to make it work and how to evaluate its future potential.

1.3 Project timeline

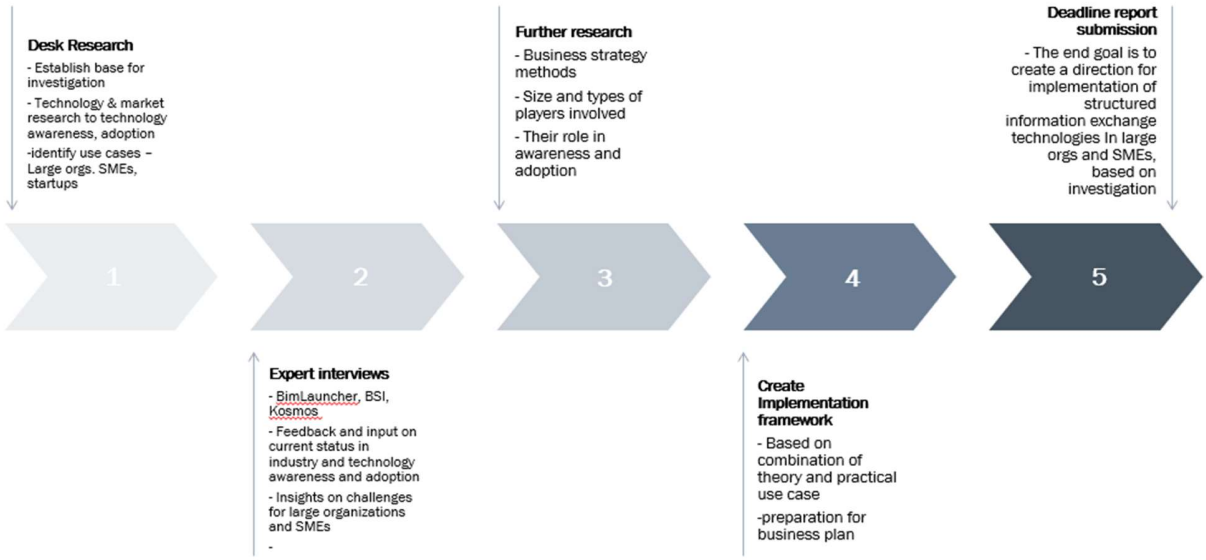


Figure 1: Project Milestones

2. Context

2.1 Architecture, engineering, and construction (AEC) industry

To better understand what the AEC industry involves, available insights on project life cycle, stakeholder involvement, and technologies within this industry are prudent. Starting with a construction project life cycle, the diagram below shows stages of the life cycle starting from initiating the project to design and planning followed by on-site construction phase and then to the final hand over of a project.

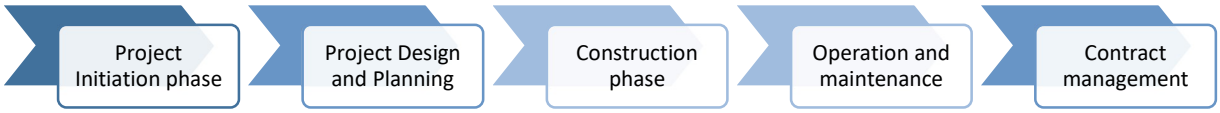


Figure 2: Project life cycle

There are numerous different stakeholders and domain experts who constantly coordinate and collaborate with each other throughout these stages. The types of stakeholders range from technical, non-technical to top management: clients, owners, consultants, domain experts like architects, structural engineers, MEP, contractors, public authorities, manufacturers, vendors, supply chain and the end-users who will be occupying the building post-construction.

However, the highest level of collaboration and communication occurs in the first three stages of the project life cycle. According to a 2014 Box report about The Information Economy: A Study of Five Industries, external collaboration in the construction sector is roughly double that of the other industries like software, media & entertainment, financial services and manufacturing (Box, 2014). These external stakeholders generate, obtain, process, and transform information from various sources and integrate heterogenous information resources through all stages of the construction life cycle. The type of information exchanged range from contract/tendering documents, PDFs, drawings, 3-dimensional models, analysis models, construction documentation etc.

The information is exchanged through various kinds of technologies, platforms, processes, networks, and servers. Some examples of mainstream and emerging technologies in the AEC industry are BIM (building information modeling), AR/VR/MR (Augmented/Virtual and Mixed reality), artificial intelligence, the internet of things, cloud computing and big data analytics (Deltek; Clarity, 2019). With the interplay of communication and collaboration with such complexity and fragmentation, issues with interoperability within various systems to systems and humans to systems emerge. Other uncertainties also emerge, like whether the end-user of the data generated and exchanged to, can interpret, and understand the information the way they

are supposed to or whether do they know how to extract information relevant to them from the whole data package, and more importantly, whether they can reuse data that is already existing to save time and effort.

2.2 The "need"

To address interoperability issues within systems and different stakeholders, there is a need for better and more effective cross-functional collaboration and integration which can be achieved through standardizing processes and methods. Bringing uniformity and structure to the information and the ways they are exchanged would alleviate the uncertainty of users misunderstanding of data, increase the quality of data generated, processed, and integrated from various sources.

There are also indications from stakeholders towards a want and desire for better integration of data and easy accessibility of the data exchanged. According to a study conducted by Dodge Data & Analytics and e-Builder, from owners and contractor perspective, the vast majority of owners value having a single project platform where they can exchange data with contractors easily. Around 73% reported that duplicate entry negatively impacts their productivity, while 70% report it slows their information workflow and 62% report it impacts their frequency of data entry errors. (Dodge Data & Analytics; e-Builder, 2019).

Keeping the above issues in mind, one must also be aware of the types of users processing and transforming the data. It is important to make sure such processes, methods and technologies that aid standardization are understood by all kinds of users, whether technically oriented or not. Hence, there is also a need for simplification of these processes and methods so that the users can adapt to the changes and help streamline the exchange of information.

Moving towards industry trends, AEC firms are already aware of the significance of planning the implementing of technologies that aid the existing processes. According to the 41st annual Deltek Clarity Architecture & Engineering (A&E) Industry Study, AEC firms are "applying technology trends to project execution and project management as part of their strategic plans to earn a

tangible return on investment". (Deltek; Clarity, 2019). The below figure also indicates the education of staff on such trends as well as identifying and developing technology subject matter experts to be another significant initiative to work on.

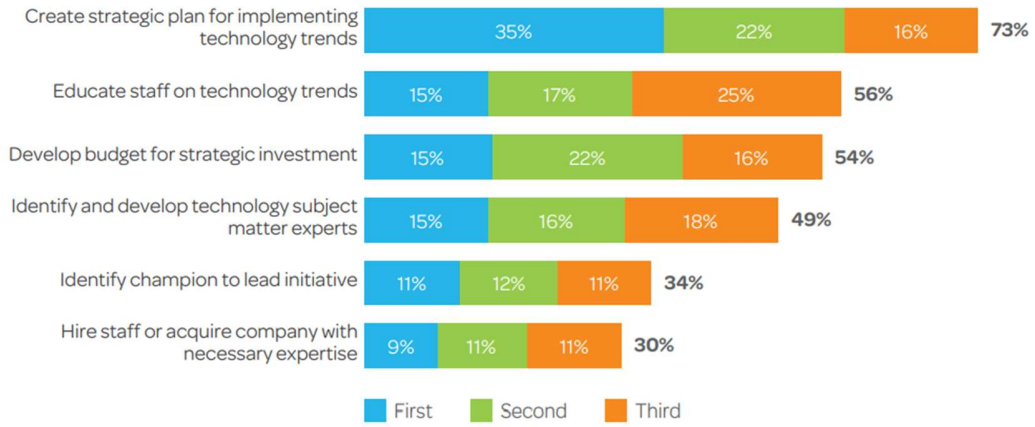


Figure 3: Top Three Technology Trend Initiatives (Deltek; Clarity, 2019)

In terms of implementation of technology trends, according to the study, *"…although large firms tend to have a closer eye on emerging technology trends, small and medium-sized firms are starting to take note.*". Additionally, large firms highlight that small firms not only misunderstand key trends, but also lack a strategic plan to implement them. Moreover, the study indicates challenges firms are currently facing. As seen in the figure below, 61% identify the cost of technology as one of the top three challenges for emerging technologies. In comparison, 55% identified the process of prioritizing which trends are relevant to the business as challenging, and 44% taught employees about trends and their applications. In other words, awareness and adoption capabilities are another challenging aspect. (Deltek; Clarity, 2019)

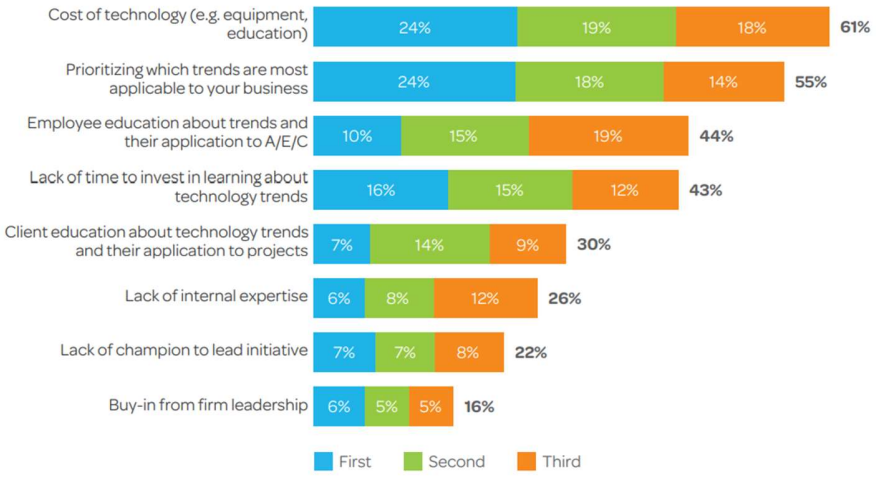


Figure 4: Top Three Technology Trends Challenges (Deltek; Clarity, 2019)

To summarize the needs and desires of the AEC industry, there is a need for standardization, easy accessibility of data, simplification of such processes and methods for better understanding and to address challenges with implementing emerging technologies, especially for firms to prioritizing which technology trends are relevant to their business to implement.

2.3 Existing efforts within the AEC industry

As evidenced in the above section, the AEC industry is aware of the internal forces pushing towards the needs of its stakeholders, and it has already seen existing efforts initiated through some of the AEC stakeholders. However, it has realized that external influences from other industry domain, for example, IT and computer science – has started to influence and bridge the gaps within the industry.

Efforts like introducing the concepts of building information modeling, Industry foundation classes, Classification systems and ontologies has made it possible to implement innovative solutions for integrating various kinds of data in practice. There are also initiatives to standardize the exchange of information through community organizations like BuildingSmart international and international organization for standardization. However, emerging technologies and concepts like linked data, graph databases and the semantic web are now gaining relevance within the AEC industry to aid the existing initiatives. These technologies and concepts are

already mainstream in the IT industry with likes of Instagram, Facebook, and LinkedIn using graph databases and linked data to connect information, objects, and relationships to create a sophisticated web of information for better data usage. The following section will discuss concepts, technologies, and methods the AEC industry is currently using. It also gives an insight into what the emerging concepts, technologies and techniques are capable of and the benefits and challenges of implementing these emerging technologies in practice.

3. Structured information exchange

3.1 Background – technologies and methods

The construction industry is complex due to the involvement of multiple stakeholders with diversified domain experts and specialized disciplines involved in various stages of the project life cycle. While these domain experts use different tools and applications to create, share, and transform information, there are many tools and platforms used by the various disciplines. This has resulted in the need for collaboration among both domain experts and specialized fields. It led to the higher significance of interoperability within different human and system interactions. Interoperability is a crucial aspect of facilitating the business processes of the industry (Pauwels, 2018). Interoperability is the effective and efficient exchange of information between different systems, networks, applications and stakeholders in an automated, accurate and agile manner. (Borrmann *et al.*, 2018).

The issue of interoperability has surfaced now, more than ever. This interoperability issue has created a need for a structured and unambiguous way of representing information so that there is a universal and standardized way of information exchange among all the stakeholders, domain experts and disciplines involved in the whole life cycle. Once the information is represented and formulized in a systematic and machine-readable format, the various stakeholders will be able to take potential advantage of automated systems and processes and overcome the issue related to interoperability within the construction industry. The following sub-sections will go in-depth with the existing industry-wide methods and emerging technologies that alleviate the issues

mentioned above. For the purpose of technical understanding, the 2018 Springer book on Building Information Modeling Technology Foundations and Industry Practice was used as a reference for investigating the method and technologies for structured information exchange (Borrmann *et al.*, 2018).

3.1.1 Building information modeling

The concept of Building information modeling (BIM) has been around for a while within the industry. Its popularity and implementation, however, has just been increasing as it has only reached technical maturity in the last couple of years, paralleling the popularization of digital transformation in the previous decade.

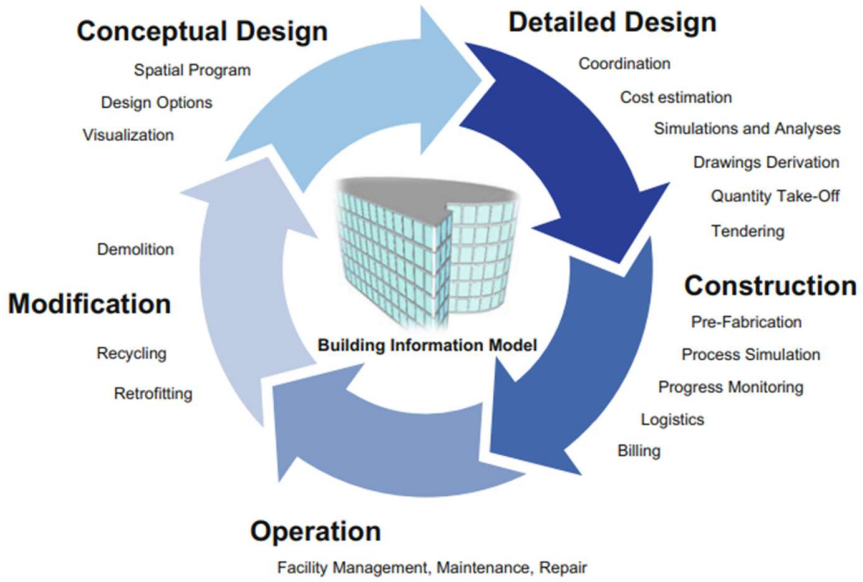


Figure 5: Building Information Modeling Concept (Borrmann et al.,2018, Chapter 1)

BIM is an information management method based on the consequent use of digital models and consistent, continuous and low-loss handover of digital information across the entire lifecycle of a built facility, including its design, construction, and operation (Borrmann *et al.*, 2018). BIM provides high-level digital representation and constitutes both 3D geometry of building components and a comprehensive set of semantic information, including function, materials and

relationships between the objects. (Borrmann *et al.*, 2018). As illustrated in the figure below, BIM shifts planning effort and design decisions to earlier phases, making it possible to influence the design performance and costs of the resulting facility before changes start to become costly to implement (Borrmann *et al.*, 2018).

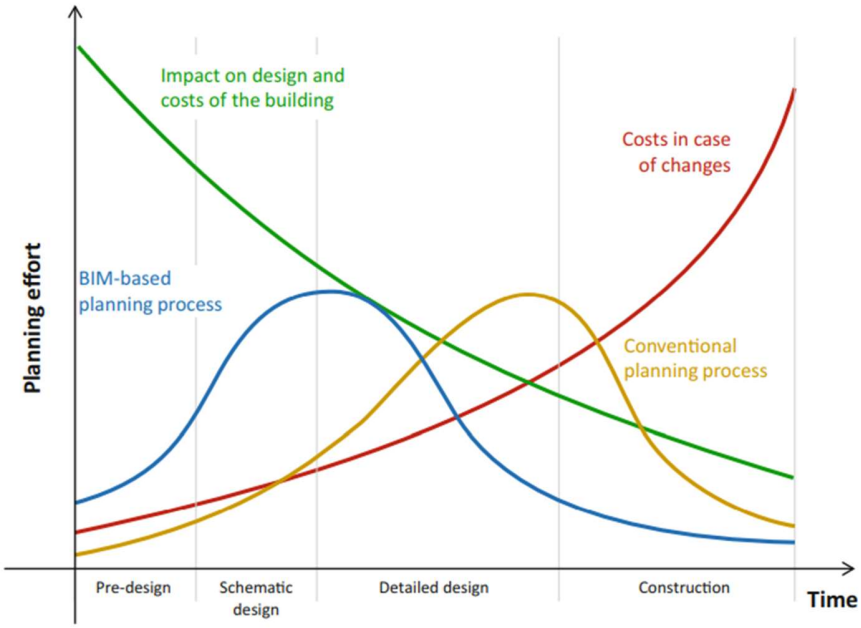


Figure 6: BIM-based planning process (Borrmann et al.,2018, Chapter 1)

There are a variety of BIM technologies being used in practice today. Currently, technology and software vendors like Autodesk, Bentley and Dassault systems develop sophisticated software solutions to provide the technical foundation for BIM implementation and standardizing data representation and exchange. Some examples of such technologies are Autodesk Revit, Navisworks, ArchiCAD, Vectorworks, Tekla to name a few, that aid in creating and sharing layers of information within a singular model environment. However, the challenges of accepting BIM have been in making the suitable models and tools in the most advantageous ways, with significant changes, new development and establishment of the corresponding workflows and processes.

With regards to methods used to exchanging information and what stakeholders store and how they send the data, an insight from the interviews also suggested "*The data which can be sent is*

limited by means of interpretation of the receiver. Currently, most document-based data is being sent as PDFs 2D and text information or as schedules in Excel. Increasingly entire Revit models are being sent, usually without proper separation to subsets, but as an entire model."

3.1.2 IFC (Industry foundation classes)

Within the construction industry, uniform standards are difficult to enforce and to achieve the goal of implementing BIM in different disciplines and life cycle phases, a vendor-neutral, open and standardized data exchange format was needed (Borrmann *et al.*, 2018). Hence, Industry foundation classes (IFC), an open, vendor-neutral data exchange format, was developed by the international organization buildingSMART. IFC is a complex data model with which it is possible to represent both the geometry and semantic structure of a building model using an object-oriented approach. The IFC data model is crucial for implementing BIM concepts and is the basis of many standardization initiatives at an international, European, and national level (Borrmann *et al.*, 2018).

The practical implications of IFC model are complicated, as the vast amount of information that is captured in attributes and properties at the geometric level expands through all the stages of the building life cycle and the flexibility of the data model makes it intimidating and challenging to capture and retrieve relevant information in an appropriate form. This led to a need to agree on a uniform and standardized means to specify further the contents expected from the model. Hence, the buildingSMART organization developed a Model View Definition (MVD) which helps reduce room for interpretation and makes it easier to implement specific use cases and application areas. The framework distinguishes content-related requirements captured in Information Delivery Manuals (IDM) and technical implementations and mappings of these requirements in the form of MVDs (Borrmann *et al.*, 2018).

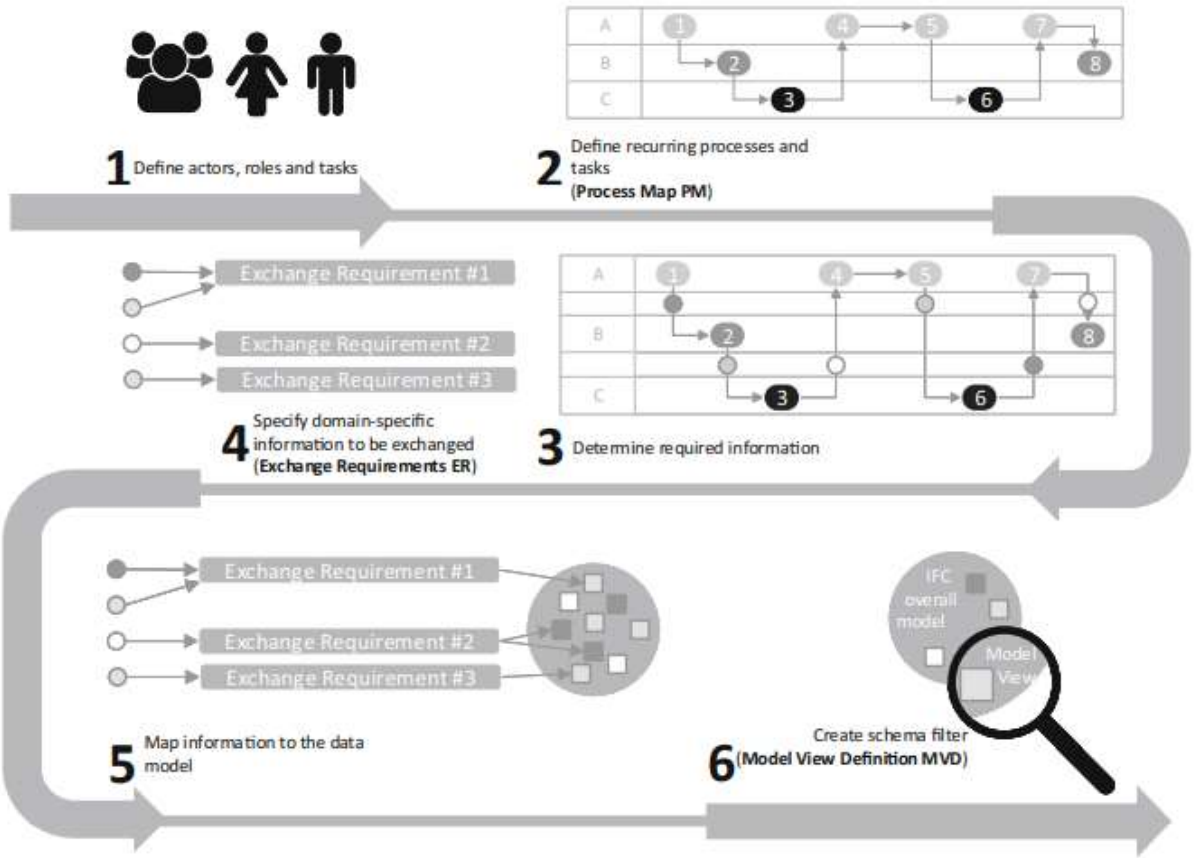


Figure 7: Overview of IDM/MVD method used for IFC based exchange of information (Borrmann et al.,2018, Chapter 6)

The above illustration is an overview of the partial processes under consideration for a particular exchange, and to organize different information exchange scenarios; process diagrams are created using the Business Process Model and Notation (BPMN) (Jakob Beetz, 2018).

These structure a number of process properties:

- Actors and their relationships (who transmits information to whom)
- Dependencies regarding the order of partial processes (when is information transmitted)
- Documents or partial models being used (what is transmitted)

The creation of model view descriptions turned complicated and laborious process. Other restrictions with the existing IFC model were the complexity, rigidity, lack of user's ability to modify and use dynamically. To address these issues, linked data, graph data models and ontologies integrated with IFC. IFC schema of structured data and ifcOWL (ontology

representation) aides' interoperability and reasoning making it more flexible, robust, and dynamic as per the needs of the customers & stakeholders.

Another insight from the interviews also mentioned that "*one of the gaps that could be potentially addressed with emerging technologies is to create data subsets by the sender, which are relevant and readily available to the receiver. The concept of MVD is very important, but as proposed by IFC, too cumbersome for a typical user. An easy, user-friendly interface is imagined, where a subset can be checked against the receiver's information requirements, and automatically and semantically queried by an algorithm to aggregate only relevant information. This can be achieved by having a holistic model database in the cloud.*"

An alternative and complementary approach to specifying design and planning requirements using IDM/MVD is the concept of "Level of Development" (LOD) or "Level of Model Definition" (LOMD) for determining which information has to be delivered by whom at which stage (Jakob Beetz, 2018).

- LOD 100: The model element is represented graphically by a symbol or a generic representation. Information specific to the element such as costs per square meter can be derived from other model elements.
- LOD 200: The model element is represented graphically in the model by a generic element with approximate dimensions, position and orientation.
- LOD 300: The model element is represented graphically by a specific object that defines its size, dimension, form, position and orientation.
- LOD 350: The model element is represented graphically by a specific object that defines its size, dimension, form, position and orientation, as well as its interfaces to other building systems.
- LOD 400: The model element is represented graphically by a specific object that defines its size, dimension, form, position and orientation, along with information regarding its production, assembly and installation.
- LOD 500: The model element has been validated on the construction site, including its size, dimension, form, position and orientation.

3.1.3 Structured vocabulary, Ontologies, and classifications

Nomenclatures, glossaries, and terminologies that are shared among a single or multiple domains are basic forms of structured vocabularies, which include lists of commonly agreed technical terms and their definitions, usually arranged in a specific order, e.g., alphabetically, and sometimes also in one or more languages. Along with customary spelling (syntax) of individual (technical) terms, they often also contain short definitions of the meaning (semantics) of the underlying concepts (Beetz, 2018).

Dictionaries containing multiple languages can be transferred into simple data models that can already be used in automation scenarios. A simple application area of such dictionaries is the translation of building product catalogues, service descriptions or bid tender documents in international projects (Beetz, 2018).

Classification systems and taxonomies relate to the dictionaries and glossaries, which create additional structure. The classification of a single building component, such as a column, can be achieved using different categories, aspects or facets, for example, according to its function ("load-bearing"), its form ("cylindrical") its orientation ("vertical"), material ("concrete") or its domain ("structural column" vs. "architectural column") (Beetz, 2018). Some established classification systems are Uniclass in UK, Omniclass in US and Masterclass in Australia.

The concept of an "ontology" is often reserved for more expressive knowledge models. In full-fledged ontologies, relations are often used that are rarely represented based on principles provided by formal logic, that make it possible to draw conclusions (inferences) based on statements or facts (axioms) (Beetz, 2018).

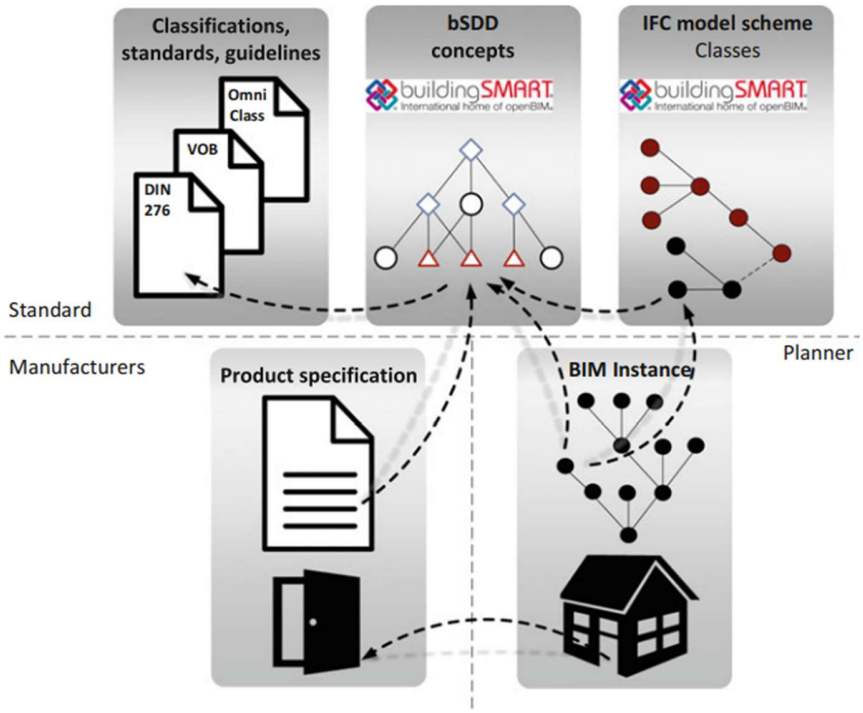


Figure 8: linking of building models, classifications and manufacturer data with the buildingSMART Data Dictionary and IFC instances (Beetz, 2018)

Dictionaries, classification systems and ontologies such as the buildingSMART Data Dictionary (bSDD) (buildingSMART 2015), or Uniclass2 (CPIC 2015) system can be used in different ways to enhance reliable collaboration between stakeholders by providing unambiguous definitions of terms and concepts. Relations and links between other object instances (a specific door or wall in a building design and its respective model) and their respective classification items ("the class of all external doors") can be created and introduced into the model (Beetz, 2018). Through the figure above, an important function of such interoperable structured vocabularies for the semantic annotation of objects is their use in building product databases (Beetz, 2018).

3.1.4 COBie

As per the definition and description of COBie in the 2018 book - Building information modeling, Construction Operations Building information exchange (COBie) is a specification that evolved from the idea of Computer Aided Facility Management (CAFM)(Borrmann *et al.*, 2018). The specification describes processes and information requirements which streamline the handover

of specific data from the design and construction phases to the facility's operation and maintenance (FM) (Schwabe K, 2018). The key idea of COBie is to incrementally gather and systematically store relevant information in a digital form as soon as they emerge in the project (Schwabe K, 2018). To realize an effective data exchange and to guarantee market neutrality, the COBie specification suggests open formats, such as Extensible Markup Language (XML), SpreadsheetML or the IFC STEP format (Schwabe K, 2018). These formats are meant for system-to-system data exchange (Schwabe K, 2018). COBie defines a hierarchical data structure for the efficient building information exchange from the preoperative phase to the facility's maintenance (Schwabe K, 2018).

COBie data mainly provides non-geometric building information, collected during the design and construction phase by different actors incrementally. It simply takes existing technologies and applies them to the process of data exchange during project handover. The corresponding technologies are open exchange formats (IFC) and subsets of IFC data (MVD) (Schwabe K, 2018). COBie specification was designed to be interoperable it can be realized using different file formats, such as IFC (buildingSMART 2013), XML, or SpreadsheetML. COBie files contain information about maintenance, operations and asset management which is provided at different project stages mainly by designers and contractors (Schwabe K, 2018).

COBie is still at early stages, due to wrong understanding of end users as well as insufficient software implementation (Schwabe K, 2018), there is a long way for its industry wide acceptance as it still needs optimization and simplification for the users to take benefit out of its practice.

3.1.5 Semantic web

One of the rudimentary problems in structuring knowledge and information for automated processing is the heterogeneity of technical representations. There are numerous classification systems, ontologies, terminologies, and vocabularies being generated using different modeling languages and formats. The problem is that till now, regardless of the industry effort to overcome interoperability issues, there are no facilitation for the semantically unambiguous exchange of information in the building industry (Beetz, 2018). This is where semantic web comes into play for distributed modeling and access to information. The idea is to standardize generic means of

modeling and representing knowledge and information that enables their uniform, decentralized creation, and the publication and linking of resources in a global network (Beetz, 2018). This will provide cost-efficient ways to publish information in distributed environments, increase bandwidths and lower cost of data storage (Bauer and Kaltenböck, 2011).

The Semantic Web is an extension of the current web in which information is given well-defined meaning, better enabling computers and people to work in cooperation. For the semantic web to function, computers must have access to structured collections of information and sets of inference rules that they can use to conduct automated reasoning (Berners-Lee, Hendler and Lassila, 2001). Hence, to get the full benefit of such open format of distributed modeling and access to information, AEC industry wide standards are required to be established.

3.1.6 Linked data

The idea of Linked Data is a descendant of the semantic web (Bauer and Kaltenböck, 2011). Linked data is used as a method to create global database of linked things, so that it can be interlinked and become more effective. It is the approach in which machine-interpretable information is interconnected in a more agile manner. This approach is in very active use across many different domains (healthcare, biology, publications, media, geography, and so forth). In recent years, many vocabularies and other data sets have been published for public access to be reused and help to collectively build up a body of knowledge in different domains (Pauwels, 2018).

In order to use linked data, there is a need for new method of data representation with suitable data formats. The existing IFC exchange format model has a challenge of not being accessible and processed using linked data technologies. There are many different information silos created by variety of technologies to be accessed by multiple different stakeholder that are still not transferable and readable. To enable the use of Linked Data principles with domain-specific Building Information Models, the information generated by common BIM tools must be represented with the suitable data formats (Pauwels, 2018). To answer to the need for better interoperability among different domains, translation of both data schema and Instant model led to international standardization of ifcOWL- ontology web language representation through

BuildingSmart standardization organization. What this does is translate the existing standard IFC model to RDFs and OWL model vocabularies which creates a meta data for buildings that helps export data without any information loss.

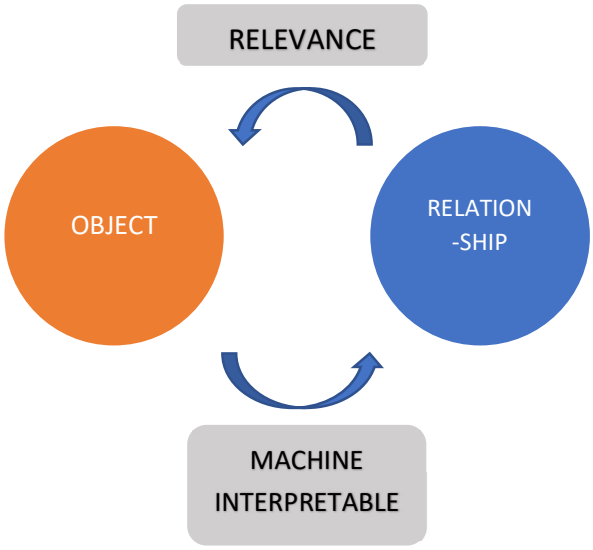


Figure 9: Linked Data concept

To give a deeper insight of many integrated technologies within Linked data and semantic web which are standardized by the W3C, the following are brief descriptions for those technologies (Pauwels, 2018):

- Uniform Resource Identifiers (URI) form the backbone of the WWW by providing means to address resources. Their most common form is the Uniform Resource Locator (URL).
- Extensible Markup Language (XML) is the common Markup Language to describe file content, provide simple data types, and can be used as a syntax format.
- The Resource Description Framework (RDF) is a data model that specifies the use of triples to form statements as well as additional concepts such as lists, bags, sets and containers. Even though RDF can be written in the form of an XML document (RDF/XML), other formats such as Turtle or JSON-LD can be used to serialize RDF into files. Larger RDF data sets are often stored in specialized databases referred to as triple stores (or quad stores), that can be accessed, linked, and queried over regular network structures. RDF ▸

Resource: pages, images, videos, everything that can have a URI ▸ Description: attributes, features, and relations of the resources ▸ Framework: model, languages, and syntaxes for these descriptions ▸ Data model to describe things and their interrelations ▸ Knowledge always comes in three ▸ RDF is a triple model -knowledge is broken down into (subject, predicate, object)

- The Resource Description Framework Schema (RDFS) provides a vocabulary to capture concepts as classes, create sub-class relations and specify possible data types and value ranges.
- The Web Ontology Language (OWL) provides a modeling vocabulary that extends RDFS with formal logic concepts (Description Logics – DL) to define additional constraints such as cardinalities or value restrictions. OWL is rooted in earlier Knowledge Engineering vocabularies and enables logical inference (reasoning).
- Similar to SQL for relational databases, the Simple Protocol and RDF Query Language (SPARQL) defines a query language to create, read, update and delete data from RDF data sets in a standardized way.
- The Rule Interchange Format (RIF) and Semantic Web Rule Language (SWRL) can be used to define rules for concepts and their relations in an IF–THEN form.

The following illustration is a graphical representation of the above technologies within the linked data and semantic web.

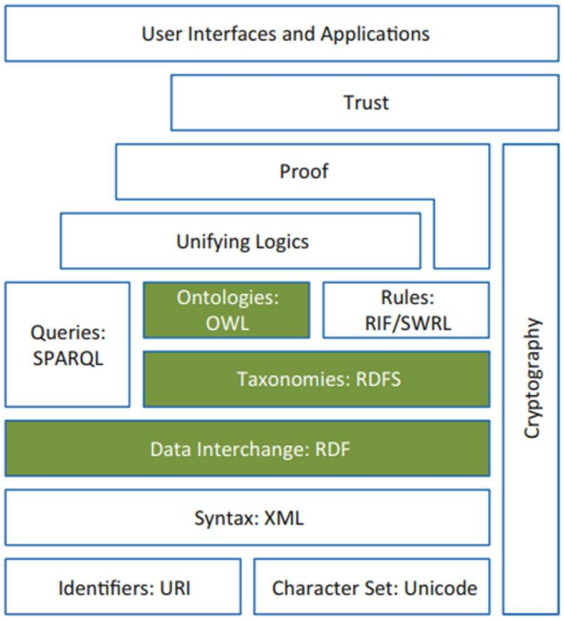


Figure 10: Semantic Web Stack

The Illustration of the Semantic Web stack is showing the different technology standards enabling Linked Data and the Semantic Web. Lower tiers show the commonly shared technologies such as URIs, Unicode and XML, which are also used in hypertext documents for the World Wide Web. The Resource Description Framework (RDF) and the schema for modeling vocabularies for taxonomies (RDFS), ontologies (OWL) and Rules (RIF, SWRL) together with the query language SPARQL form the core. They form the basis of the more conceptual layers around Logic, Proof and Trust. The main principles lie in the possibility to interlink heterogeneous information resources using the URI, XML and RDF tiers of the stack (Pauwels, 2018)

In other industries and knowledge domains, the linking, reuse and integration of different vocabularies and data sets has been rapidly growing in recent years and has led to a vast web of interconnected information resources referred to as Linked (Open) Data (LOD or LD). Linked Open Data principles to follow, to make data interconnected (Bauer and Kaltenböck, 2011).

- Use URIs as names for things
- Use HTTP URIs so that people can look up those names.
- When someone looks up a URI, provide useful information, using the established standards (e.g. RDF, SPARQL)

- Include links to other URIs, so that more things can be discovered

Linking information from different sources is key for further innovation (Bauer and Kaltenböck, 2011). Linked Data technologies can be used to link models and other building data in a decentralized manner, preserving the data ownership and digital sovereignty of the owner to authorize users and determine the terms and conditions for data use (Törmä, 2013). The concept of such linked models is to relate objects representing the same physical design artifacts with additional relations that explicitly state which partial domain aspects they represent (Pauwels, 2018). Below illustration is the cross-model linking between the elements in the models from five different stakeholders that can be achieved through common linked data technologies.

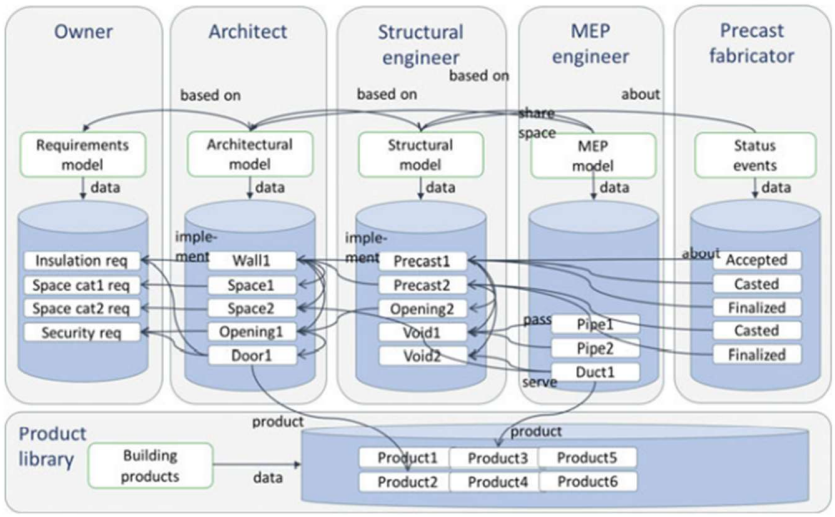


Figure 11: Interlinked models using specialized relationships (implements, serves, spatial overlaps) (Pauwels, 2018)

Using common linked data technologies and formats, the centralized model can be queried and processed using standardized languages and available tools such as SPARQL and information is available through the link between the objects. At the moment there are not any commercial systems available that fully support such interlinked models, but standards like upcoming Information Container Data Drop (ISO 21597) will define object-level links between different models, documents and data sets using Linked Data technology (Pauwels, 2018).

3.1.7 Knowledge graphs and graph database models

Graph theory and graph thinking is used to model relations between objects. The data representation is in the form of graphs. Graphs represent entities as nodes and the ways in which those entities relate to via relationships. The entities that are represented as nodes contain properties with further information. Multiple nodes are connected with edges that represent relationships that connect them and can be labelled with properties. Graph data aids in leveraging complex and dynamic relationships in highly connected data.

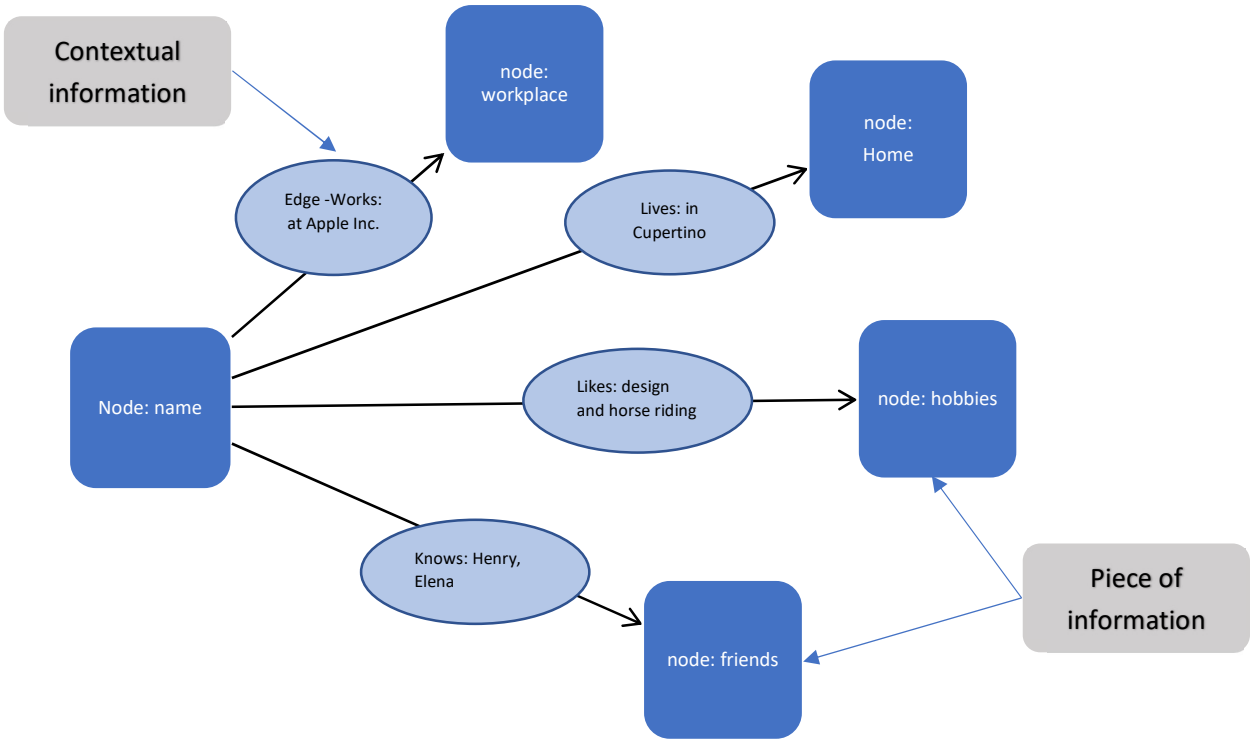


Figure 12: Graph Data Base Concept

Some examples of where graph data is being used and implemented would be – LinkedIn, Facebook and Amazon (Saarela, 2020). Companies use graph data models to go through immense amount of data to identify relevant patterns among the relationships and use that information to identify new relevant user needs and cater to better user experience. Everyday example would

be the relevant suggestions of products or similar products to recently purchased items that you can see in your amazon or social media accounts like Instagram or Facebook.

Graph data technology offers agility, modularity and scalability when implemented (Saarela, 2020). It aids in increase in performance especially in handling large and ever-increasing amount of data, more over it helps make relevant connections with independent and heterogeneous data information silos. That in turn, increases analytical capabilities of business, aids smarter decision making for businesses and ultimately business end up improving their business processes, increasing their ability to be more favorable to different types of customers/stakeholders. The ease in interoperability makes this set of technologies more fitting to be used in construction domain (Saarela, 2020).

Generally, organizations tend to have a data management system set up to place all the data for specific projects in one singular location, i.e., master data. Data handling activities like collected, consolidated, analyzed, edited, distributed within and external to the organization involves multitude connections and relationships which can get challenging to manage through relational database (type of database that uses table format to structure relations between pieces of information) (Saarela, 2020). Graph data technologies can help manage contextual information and querying for information in an efficient and effective method. However, effort from multiple stakeholders is required to implement graph databases and be able to use it to link different kinds of data.

3.2 Advantages of mentioned technologies

Implementing standardization to how all types of stakeholders represent and exchange data aids with establishing homogenous format for the industry to follow. If the industry pushes towards implementing standards and relevant technologies, one of the advantages would be alleviating misinterpretation and misunderstanding of data exchange throughout the life cycle. The issue of transferring information is about semantic interoperability, which focuses on human - machines readable data, how one stakeholder sends the information and how the receiver interprets it.

Focusing on such technologies also increases the capacity for system-to-system interoperability, which enables storage, more efficient ways of breaking down complex information and sharing it among relevant stakeholders; on top of reducing loss of information and maintaining integrity in quality of information.

Holistically, one can achieve higher quality semantic representation with more degree of meaning, better intelligent processing and reasoning leading to higher quality of information exchange and automation of repeatable, specific, and scalable tasks and processes.

In terms of long-term value, as these technologies streamline and standardize internal and external business processes and tasks, it will translate to reducing amount of errors, risk reduction and cost savings for the business.

3.3 Risks of implementing mentioned Technologies

Some of the risk and uncertainties that come with pursuing technology or change implementation within an organization would be sunk cost of implementation and whether the organization will get the anticipated return on investment and validation of the value in implementation.

Another significant risk is the hindrance in the implementation of IT systems, especially if there is a lack of expertise within the organization. The risk of not having clarity on how to use the technology will also increase the probability of data security and privacy issues that could affect the whole organization.

In terms of organizational culture, if the technology is too complicated to use, as different types of users experience technologies differently, there are chances of higher resistance to change, and it will be challenging to convince everyone to come on board with the process of implementation.

3.4 Potential drivers for change

Currently, one of the main drivers for change is industry trends like the digital transformation that are influencing the level of awareness for need for standardization, easy accessibility and exchange of relevant data and addressing the challenges that come with implementing and establishing the format for the industry to follow.

Technical and professional communities such as BuildingSMART have attempted to standardize construction vocabulary for industry-wide usage. Such communities also aid with sharing case studies, networking, exchanging knowledge between domains and inculcating innovative processes and holistic solutions to address the needs of the industry. Organizations and standardization bodies like the British standards Institution, International standards organization, National BIM standards-USA, ASHRAE, and BIMForum have already started steering the industry towards gaining homogeneity and implementing standards in data representation and data exchange.

There are also other technical online communities, forums and organizations that act as platforms for bringing together technical and non-technical people from various organizations, who want to seek, explore, ask technical questions, and exchange knowledge and ideas. They play a huge role in building an environment for Learning-applying-teaching.

Technology vendors like Autodesk, Bentley etc. are also complying with and getting their products and services certified for standardization. While other top-down forces, like Client and government mandates, for using technologies and standards, on projects are pushing stakeholders to start adopting standardization within their workflows and processes.

3.5 Main takeaways of the internal investigation

A couple of main insights regarding the AEC Industry are fragmentation and complexity. The market is very fragmented, with various kinds of stakeholders with a small window of engagement within the project life cycle. As different stakeholders use different kinds of applications, software, and technologies, they are currently exchanging data in the form of PDFs,

2D drawings and text information, excel, analysis charts etc. There are also holistic 3-dimensional modeling software like Autodesk Revit which are sent as entire model without proper separation of data. To work towards a homogenous format for the exchange of information, for the industry to follow, there is a need for standardization.

Secondly, there is lack of awareness. The emerging set of technologies coming from other domains like IT are novel and unfamiliar to many within the construction domain, with little awareness on what can be achieved when implemented in the right way. Hence, there is fear and resistance to adapt to using the new technologies as there is lack of technical expertise.

For easier use of new applications and processes, there is a need for simplification. The level of understanding varies among the non-technical, technical, and top management stakeholders which hinders the capacity to use the new technologies. Lastly, there are implementation challenges like understanding which technologies need to be implemented, the sunk cost of implementation, and uncertainty of not having the mindset and perspective within the organization on where to start and what is ultimately needed. With the above insights in mind, the next step of the investigation was to get validation and additional insights on the status in the AEC industry. The following section will be dealing with the same.

4. Industry Analysis

4.1 Set up for Market analysis

For an in-depth understanding of the current status in the industry, a semi-structured interview template was created to gain the most valuable and relevant point of view based on experts with varied roles and responsibilities within the AEC industry. The following experts were interviewed for the purpose of gathering industry insights as well as for validation and additional insight for the proposed implementation framework:

- Stephanie Bay, Project Manager, Nohara Holding Inc.
- Adam Piaskowski, BIM Consultant, Nohara Holding Inc.

- John Egan, CEO BIMLauncher
- Rahul Shah, Sector Development Director EMEA Built Environment at BSI
- Zuzanna Czapla, Product development engineer at Bluestar PLM
- Ross Griffin, Founder – Chief Commercial Specialist of KOSMOS
- Michael Moran, founder of Telos

The following is the format and template used while conducted the interview. The goal of the interviews is to get clarity on:

- Understanding the level of awareness of technologies that aid structured information exchange in the industry.
- Gain insights on potential approach to initiate/carryout technology implementation.
- Get a clarity on the approach to implementation between large orgs. Vs SMEs.
- Do they think these technologies are helpful and relevant?

The following segments include the general structure that was followed to get some insights for the above.

Awareness

- Are organizations and stakeholders in the construction industry aware of technologies that aid structured information exchange? If so, to what extent?
- Is your organization taking initiatives towards such technology implementation/changing or improving methods of information exchange? How are you doing it? How do you/did you realized the need to implement?
- What do you think about the potentials of linked data and graph databases to aid the issue of interoperability? Are there other mainstream methods being used at the moment?
- With regards to methods used to exchange information: how do you store and send data? What kind of data is exchanged – object-specific, design and construction documentations, tender documents?

- Is there a specific instance in using such methods where you reuse of data/ aspects you have created in a more effective way?
- Do you see any gaps that could be potentially filled/addressed with emerging technologies?

Action – technology Adoption

- How long has the technology implementation in the Construction industry taken, in your opinion? (IT, BIM etc.)
- How would you compare technology acceptance in the construction industry vs other industries?
- Do you think the adoption is slow? – if yes, why so? How fast do you think will the industry take to adopt these technologies, esp. linked data and graph data models?

  The general insights are the paradigm shift is going to take a while, with the help of government or client mandate, industry associations possibly. In your opinion, how can SMEs in construction be a part of this progress? Can they do somethings to expedite the acceptance and implementation rate?

Implementation & Operation

- Have you been part of any such technology implementation within any construction organizations? For example, BIM or implementation of any methods for effective info. exchange?
- What were your insights on the gains and challenges in the process of implementation? Main takeaways? Things that should be considered before, during and maybe even after such implementation?
- Do you think there is a vast difference between processes of large orgs and SMEs when implementing such technologies?

Summary

- How open are you regarding digital solutions?

- What is your opinion on how these technologies will help lead ways to better and smarter built environment in the future?
- How would it impact construction activities in the future?

The following sub-sections will give an overview of the points of views and additional insights gain through expert interviews.

4.2 Current industry outlook

A cumulative opinion regarding the current AEC industry is that it is a very exciting time to be involved in this industry. The reason being that there is a paradigm shift that has started taking place, with digital transformation being the core trend towards which the industry is heading towards.

As digitalization has been picking up at a much faster pace in other industries like IT, manufacturing and even finance, the construction industry has been a bit slow in adopting it. This was validated during the interview as they mentioned that fragmentation and globalization play significant roles in making the construction industry lags behind other industries, especially with regards to services that are offered globally. Cumulatively, the experts agreed that one of the main reasons that this is the case is because the AEC industry is highly fragmented and loosely integrated with many specialized domain experts.

An interesting fact that was brought up during an interview is that there is always a split/battle between the client, contract and all the other stakeholders. They are not integrated, and there is no mentality of partnerships. The stakeholders are all looking at the building information as a linear process, but they need to look at it as a circular process. While gathering deeper insight on the existing mentality of the project initiation phase, it was highlighted that the budget is fragmented into smaller packages and given to different stakeholders to manage it. They are not given standards for reporting or standard processes to follow. They are just given a pool of money

to control and are asked to deliver the project for the client. Hence there are different levels of quality experience, knowledge, management of the budgets for the clients while different stakeholders are feeding information the clients. Therefore, it will take long time for changing how projects are delivered, and processes are digitalized so they can become circular in information rather than linear.

According to Rahul Shah from BSI UK, the key potential barriers in the paradigm shift within the industry are that there is no standard framework to follow, there is a need to establish a right framework and proper standards for employees, supply chain and all stakeholders involved. The digitalization process is still at an infancy stage, and the technologies are not matured yet. There is also a lack of standard skill set and a lack of legal/contractual framework established. But the general impression is that the change is coming. Ross Griffin, CEO of Kosmos, stated that "*change is coming, whether we like it or not, digital workflows are coming, whether we like it or not, automation, AI, it's coming, whether we like it or not, so we can't sit back and say, I'm not really interested in that, I'm not going to change, because, if you don't do that in five to ten years, you will be irrelevant*."

While In terms of how the different stakeholders within the AEC industry should handle digital transformation, Rahul Shah from BSI stated that "*…all organizations should approach digital transformation and implementation as change management*." There was also a collective understanding that the paradigm shift will take time as the industry has just recently started to push towards a structured way of exchanging information which would be achieved through standardization.

Mr. Griffin also mentioned that standardization in building information is achievable and that from his cost professional perspective, "*standardization is the key*". In his opinion, "*every construction project is the same, even though people say it is not as they have different sizes of buildings and different functionality. Still, every building has a foundation, every building has a wall, every building has a slab every building has a roof, windows, doors, so if you break it down to the elements. Every building is the same; it is just different variations of those elements. So, from a cost perspective, we should be able to structure how we manage cost, how we report costs,*

how we collect cost data, and we start looking at this circular process and building the banks of data in order to be able to in the future, automate, perhaps use AI to analyze."

The experts also gave significant insights on the industry-wide efforts for standardization especially, standards published by BSI and ISO. Some mentioned examples are:

- BSI- ISO23386-ISO 23387 - methodology for providing unambiguous definitions using standardized data structure;
- BSI- ISO 56002:2019 - Innovation management, Innovation management system Guidance;
- ISO 12006-3 - framework for object-oriented information;
- ISO 23387 - data structure for data templates.

The experts also talked about an international organization like buildingSMART which has realized the need to create scalable interoperability for data standards, tools and the underlying technologies to facilitate more connectivity between domains (buildingSMART, 2020). With regards to efforts for creating homogenous classification systems, according to Adam Piaskowski "*currently, creating a system which can account for all possible variations is quite gruesome. Attempts had been made by vendors such as Autodesk and by communities such as Building Smart to standardize construction vocabulary.*"

There is already a top-down influence on the industry shift, but there is still a lack of influence from the bottom up; not all the stakeholders are at the same level. What needs to change within the industry is all the stakeholders need to loosen up and be willing to challenge some of the traditional mentalities of working with data, especially when it comes to handling data transparency.

4.3 Technology awareness and maturity

With regards to the level of maturity of the mentioned technologies that aid structured information exchange, the experts validated the fact that there is a lack of awareness, but also that there is a need for demonstration for the same. The emerging technologies like graph data

bases and linked data are influenced from other industries like IT, so even though these technologies are mainstream and are being used by the likes of Instagram, LinkedIn and Facebook, it is still novel within the AEC industry.

According to John Egan, CEO of BIMLauncher, he finds that "*organizations and stakeholders within the construction industry are not aware of these technologies, and they do not have the innate understanding of the technology. It is challenging for people who do not have the IT know-hows*". The stakeholders are looking at the technology from an outsider perspective as "*they don't understand the internet and the different layers involved, that would help inform the real insight to the technology. Because they do not have the fundamental understanding, they can't make abstractions and innovate.*"

However, the concept of structured information has been around a while and the concept of BIM has been popularized and implemented within many organizations across AEC industry in the recent years. Adam shared that "*structured information has been in use since the CAD first been used in 1950s by the MIT. With the advent of classifications such as sfb (1959), structured info exchange was a key to communication even prior to the discovery of BIM in the 1974, by Charles Eastman's influential paper "Check for design regularity". Currently, the same holds true, design in Japan is already somewhat standardized through materials and categorizations, so the question is which technologies are being used and to what success.*" So, there is an awareness of the need for standards, but there is an undistributed level of technical knowledge needed to work with those technologies. These interview insights bring focus on the question of how businesses need to realize and identify which technology trends will cater to their growth.

4.4 Current Industry adoption

A cumulative insight is that the adoption has been slow and that immense effort and collaboration between the IT sector and the construction sector is needed for the rate of adoption to increase. Another fascinating insight is the main reason why classification systems are not utilized are to the fullest:

- Margin is tight,
- Barely any investments in R&D,
- Stuck with traditional ways of working,
- Clients need to mandate it.

The adoption has to be client-led, as the client has to evaluate and realize that there is value in adopting standards in terms of controlling the project in terms of cost management and content, reducing the risk of overrun on budget, reducing the risk of errors being made and misinterpretation. This is a top-down approach, as clients, especially government clients, are the biggest kind with huge projects ranging from infrastructure, airports, railroads, hospitals etc. The hope is that starting implementation of standards and technologies from large infrastructure projects and then let it filter down to small scale projects will aid the pace of adoption. But there is no guarantee that this will be the case as the changes that need to be made are at multiple levels. An external counter force coming into play are the external users, developers, and modelers from outside the building domain. They are coming up with a solution to fill the gaps within the industry, which is attractive as these forces can take the form of additional stakeholders taking part with the whole project life cycle.

The type of information in focus for being standardized for exchange also needs to be paid attention to. According to Ross Griffin: "*We have a challenge here when we're structuring the architectural engineering design process in terms of information. We are not structuring the cost process. As we are structuring the design information, we are only structuring what we digitally produce in 3D. We are not structuring, what we do not produce in 3D is all the other aspects of our economy in the construction. We are all focusing on the 3D design aspect, which is probably 80% -75% In terms of the value of the building. In terms of the entire project includes all client fees costs, land purchases we probably only designing 40% of the project in 3D in terms of value. So, we are really focusing on the 3D model in terms of what we can do and how we can control, but in terms of value, it is a very small part of the project. And if we are only digitizing that, what happens to all this other aspect, how do we digitize that economy, if we're focusing on the 3D only?*"

There were many instances during the interview where they commented that the current technologies and solutions are focusing just on model information exchange and that there is a need to focus on documents and object-level exchange for holistic orientation. Special attention needs to be given to re-evaluating, which aspects and type of content exchanged to bring the most value to the table. Many mentioned documents should be given priority as these types of information are relatively low in volume and provide higher value to the business, and then the focus should be given to object-level exchange at the sub-document level. So, the stakeholders need to question and reevaluate what type of information brings value to them and also ask what is valuable in things they do not know what to do with. Maybe, that will help them open up and be more transparent.

4.5 Current Industry challenges of implementing

In terms of challenges, all of the interviewees validated that traditional construction firms do not produce and exchange information in a structured way and that the problem is different robust information from different stakeholders, their short life span of engagement, and lack of awareness in the utilization of structured exchange.

Other issues brought up were a lack of clarity of understanding of who takes responsibility, of what and when during the life cycle. Consideration for high cost in terms of resources (hardware and software), manpower (skills and training) also plays a role in the initial phase.

Consequently, human error, loss of data and waste/irrelevant/repeated data and data oversharing can hinder acceptance and adoption. Lack of deep technical understanding and technical experience in purging models and sending uniquely relevant information to a task at hand often hinders the speed at which the data can be reused, as it first has to be cleaned, purged, and checked against 2D documentation. As the issue gets more technical, there are not many experts within the industry. These issues add to the resistance to change in traditional ways of working.

As it requires stakeholders from different domains to get out of the comfort zone, one of the insights mentioned during the interview stage is that "*we need to look at the industry and see what levels we are talking about and where we currently are and where are our biggest issues. It is always the large capital projects, hospitals, roads, bridges, rail that are always a challenge for us. So, that is our focal point, and what we do there can filter down in some level into the smaller projects as we begin to standardize and implement standards.*" Hence when it comes to changes at the industry scale, that too in an industry as complex and fragmented as the AEC industry, we need to keep in mind that it is going to be a long-term process and that it has to viewed as an incremental change process.

In terms of future prospects of such methods and technologies, one of the aspects covered during the interviews was how these technologies would help lead ways to a better and smarter built environment in the future. An interesting point of view from one of the interviewees is that "*It is already happening, and those that are aware of the change will naturally benefit the most from digitalization and structurization of construction vocabulary. They will at least take the position of the educators of the rest if all other benefits were to be neglected."* On opinions regarding how it would impact construction activities in the future, the general view was that it is difficult to summarize to what extent it would impact as these technologies are still novel and will take time to technically develop and become a norm within the AEC Industry.

4.6 Implementation approach large vs SMEs

During the interviews, various interesting insights were discussed with regards to how different sizes of organizations are interplaying within the paradigm shift in the AEC industry. When it comes to the adoption of the digital transformation trend, it is still a minority of companies that are accommodating organizational changes. Within companies, the internal organizational structures are such that, they are tasked with delivering a part of the project, either design or construction documentation. Even if they do have people within the company that are having such perspective and the capacity to initiate changes, the challenge is they are probably guidance

role like internal consultancy, but not necessarily an authority to make final decisions. Even though there are companies that are opening more departments and roles which are tasked with that, there is a long way to go for it practiced in all sizes of organizations.

Large firms in construction tend to have higher capacity and bandwidth to invest in R&D, they can hire higher qualified experts, spend money on trial and implementation of new technologies.

Consequently, the large firms are driving innovation and industry trends. They are involved with other industry organizations and standardization bodies to strive for setting industry trends. They also are involved with users and developers from different domains who are creating innovative solutions for opportunities to integrate and develop better solutions.

On the contrary, small, and medium-sized firms within construction are not engaging as quickly as large firms when it comes to adopting and implementing. As their timespan of engagement within a project is short and fragmented, they usually are followers of these trends set by the big players within the industry. However, as changes coming within the sector are unavoidable, and external drivers like digitalization, new client-based mandates, and a better chance to thrive within a fragmented industry, SMEs need to be more involved and aware of the change coming and be prepared, if they want to stay relevant in a complex environment like the AEC industry.

Another additional perspective discussed during the interviews were that organizational changes and execution of implementation should be easier in SMEs as compared to large firms. According to Ross Griffin "*large organizations have a much more difficult task. Companies with 1000s of employees to digitizes is more difficult because there are so many moving parts, and generally, those companies are broken down into small departments, and you might have hundreds of small to medium-sized enterprises within a huge organization but still the organization needs to mandate a change in order for it to happen across the entire organization, whereas small to medium-sized businesses and startups are much more flexible because they have less. There is less politics involved*."

The insights from the interviews as well as the investigation shed light on the ongoing top-down efforts within the industry to achieve standardization, but not enough bottom-up effort coming into play. For the purpose of this report, it is interesting to focus and explore the potentials of a

bottom-up approach for the main goal of creating a framework for implementation. Hence, focusing on what small and medium-size companies can do to be a part of the industry-wide paradigm shift would be a central aspect in the upcoming change implementation framework. Keeping these insights in minds, additional desk research was conducted to understand how organizations can implement and design solutions for better agility within the firms, concept of innovation management, different methods of implementation and change management. The following section will go in detail with the theoretical ideas and methods used as inspiration within this investigation.

5. Discovery

5.1 Primary desk research for methods of implementation

To establish potential direction for the thought process and framework for strategic implementation, an exploration exercise was conducted to gather theoretical concepts, ideas, and guidelines. These variety of existing concepts were taken as sources of inspiration that helped understand and create a mental collage of ideas for implementation methods regardless the type and size of organizations. The following sections will go into detail through the theoretical concepts and idea taken as inspirations.

5.1.1 Inspiration form Contextual design for life

During the initial semester at AAU, high significance was given to various methods which focus on extracting user needs so that user-oriented design and solutions can be produced. That thought process lead to exploring the contextual design, a user-centered design process built upon in-depth field research to drive innovative design (Holtzblatt and Beyer, 2017a). Multiple aspects from the book were taken as inspiration for many segments of this investigation as well as during the exercise of identifying methods and framework for technical and organizational implementation.

For the initial stages of the investigation and planning for interview layouts and approach for relevant inquiry and even finding relevant people to interview, the following elements and ideas were taken into considerations.

- The four principles of Contextual Inquiry: context, partnership, interpretation, and focus (Holtzblatt and Beyer, 2017b)
- "Don't ask a domain expert to explain what you saw—ask the user!"(Holtzblatt and Beyer, 2017b)

The following structure for contextual interview (Holtzblatt and Beyer, 2017b) was used as inspiration for conducting interviews for the investigation for this report.

Intro: Traditional interview steps

- Introduce yourself and reveal your focus
- Promise confidentiality
- Get an overview of their life vis-à-vis the target activity
- Explore Identity elements
- Start to walk the day looking at behaviors relevant to the target activity, considering
- place, time, and platform used.
- Deal with opinions about tools
- Switch to Contextual Interview
- Reset the rules to observation and discussion, not Q&A

Observe and co-interpret

- Take notes
- Follow your activity focus
- Follow your focus for selected models
- Look for Cool specifically
- Be nosy

- Interruptions are data too
- Beware: Cool data is more retrospective. Ground yourself in real story and detail!

Wrap-up

- Create a large interpretation of your learning about the activity in the context of life
- Share your rough model drawings and Cool takeaways
- Ask "pet" questions
- Thank the user

In terms of the philosophy behind designing for life, for users, the book mentions the Cool Concepts, which define how cool products touch our core human motives and show how products enhance the joy of life, how they make our lives richer and more fulfilling. It aligns with the idea of simplifying solutions to cater to all types of audience. If the product/service caters to the ease of application of any type of technology, it will be influencing the speed and level of acceptance by end-users.

In terms of project planning and execution, the book emphasizes the value of a person skilled at project leading who can keep the team organized and moving forward and who can corral participation from whoever is needed. Without that person, nothing gets done. Planning, keeping all the details and people organized, and being very clear on the goals and focus of the project to make sure it stays on track—these are all must-have skills for any Contextual Design team (Holtzblatt and Beyer, 2017c). It also mentions the importance of having cross-functional teams - user researcher, interaction designer, product manager (or equivalent in a business), and an engineer who knows the technology (Holtzblatt and Beyer, 2017c).

Even though these insights are for product development and user-centric product innovation, the main takeaway that is useful for the investigation in hand is that regardless of how efficient the technology, product or solution can be, the challenge is to figure out if the end-users are able to use the technology to enhance their workflows and get their job done without further consequences that hinder their experience.

5.1.2 Inspiration from standardization institutions

British Standard Institute (BSI) is the UK national standards body that develops international, European, and British standards. Founded in 1901, BSI represents UK interests at the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC) and the European Standards Organizations (CEN, CENELEC and ETSI). (BSI, 2021). They publish over 3,100 standards each year, underpinned by a collaborative approach, engaging with industry experts, government bodies, trade associations, businesses of all sizes and consumers to develop standards that reflect good business practice, protect consumers, and facilitate international trade (BSI, 2021).

One of the BSI standards publication is ISO 56002:2019, which is UK implementation of BSI Innovation management guidelines (ISO, 2019) indicates that organizations should determine external and internal issues that are relevant to its purpose and also determine areas of opportunity for potential value realization. For example, such external issues could be identified through scanning and analyzing exercises like PESTEL (political, economic, social, technological, environmental, and legal) analysis or SWOT (Strength, weakness, opportunity, and threat) analysis. These methods could also give geographical scope to achieve like international, national, regional, or local and clarity on their respective implications on strategic and business decision making. Such analysis can also provide insight on the speed of and resistance to change, current trends and the impacts of such trends and can provide a better understanding of where the company is currently positioned and where it needs to head towards.

According to the standards, Internal issue can be determined through analyzing its core competencies, capabilities, and assets. The company should revisit its vision, ambitions, strategic directions and existing organizational structures and management practices and systems. Moreover, ISO 56002:2019 signifies evaluation of innovation competencies and organization performances, especially operational aspects, e.g. processes, budgeting, controlling, and collaboration and also understand the potential and maturity (position on the life cycle) of current offerings and value realization models (ISO, 2019). The standard also mentions that organizations should consider the adaptability of strategies, processes, resource allocation, as

well as cultural aspects such as values, attitudes, and commitment at all levels of the organization as they can be influential factors when evaluating implementation and planning for it (ISO, 2019).

In terms of planning, the standard pointed out organizations should take into consideration actions to address opportunities and risks, the needs, expectations, and the requirements so that the organization has an assurance that they can achieve the desired outcomes while keeping in mind uncertainties associated with the opportunities and degree and type of risk that may or may not be accepted (ISO, 2019). The organizations should know how to integrate and implement the actions into its innovation management system processes, evaluate the effectiveness of these actions and how to identify opportunities that can lead to innovation initiatives. The innovation objectives should be consistent with the innovation policy and aim for the innovation vision and be consistent across functions and levels of the organization (ISO, 2019).

Through these insights from the innovation management guideline, an idea that organizations that have to bandwidth and capacity to invest should invest in an innovation manager or a change manager emerged. This person would have the capacity of getting into the company with an expertise of what the industry trends are and are able to quickly understand the company's internal workings. Ideally, a person within the company who is explorative and has a holistic view of the company could also be a good choice to take the full responsibility to guide the organization through the implementation of innovation processes and/or technologies relevant to the organization. Depending on the size of the organizations and its capacity, either one person or a team can be made responsible for evaluating, curating, and executing a plan for innovation management and implementation.

5.1.3 Inspirations from Industry events

When researching for an approach towards implementation of technologies and methods mentioned in section 3, especially linked data, an existing method was brought to attention through the "*Linked data in architecture and construction*" (LDAC) 2020 conference. The event had a segment that focused on recent developments and proposals from the industry. One of the keynote presentations was by Espen Schulze, group VP research at Cobuilder on Norms/standards, BIM standards ISO 23386 and ISO 23387. He introduced a Cobuilder platform

that helps exploit the potential of product data and provides solutions for structuring data according to applicable local and international standards while mentioning a proven step by step implementation process:

- Assess saving potential
- Set up a digital strategy
- Implementing a proof of concept
- Full implementation, country by country

The mentioned general implementation process brings attention to the need to give substantial evidence that the implementation will bring monetary value to the organization, while also focusing on the significance of catering to different types of audience: technical, non-technical and management to be successful. The concept of providing a Minimum Viable Product (MVP) could be executed when considering the construction industry and the various stakeholders and clients that are conservative about spending money. Another keynote session was of John Egan, the founder of BIMlauncher, who also talked about advancing industry productivity by connecting disconnected set of platform and the data within them and the development of distributed Common data environment using linked data (Egan, 2019). He brought up that it is important to consider that linked data technologies are still in the product development stage of the product life cycle. And that it is necessary to understand the users and their needs. The product and service should be given out for testing to users and use the feedback to improve the product/service.

5.2 Inspirations from Academic methodology

A possible inspiration is the design thinking process by the d.school, Institute of design at Stanford University (Balcaitis, 2019). The concept is creative and iterative process that can be tested in the short term to help create clarity based on user inputs and identify areas within the process/product/ service that needs to be improved. This method can potentially fit SMEs that have the capacity to be agile, test and implement multiple variations of strategies to identify the

best suitable one, without the long bureaucratic process and politics that a large organization will possibly face. The concept of iteration exercise, testing and assessing can potentially be implemented within a larger process and can be used to gain clarity or prioritize certain internal processes. Hence, it is a good point of reference to consider when thinking about an agile and iterative framework for implementation.

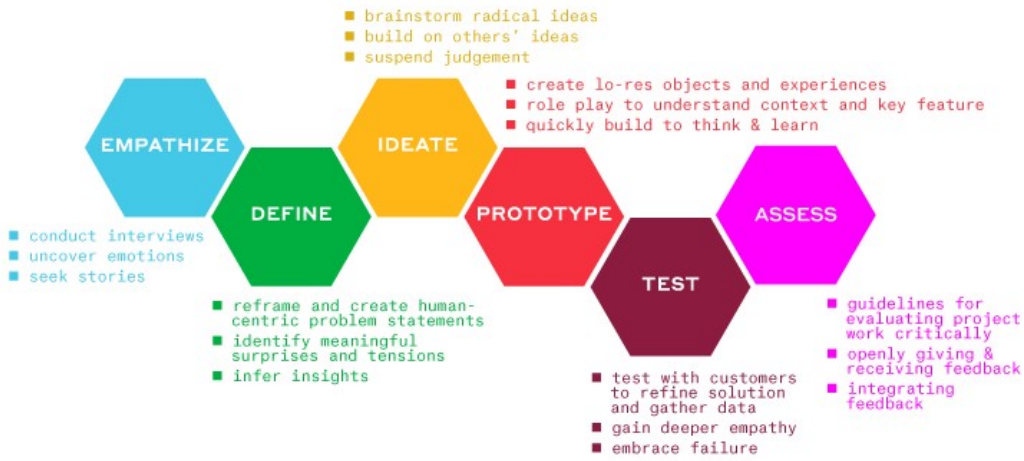


Figure 13: Design Thinking process (Balcaitis, 2019)

5.3 Theoretical models

In order to define a framework for incremental change for implementation, the following change management models and theories were considered for inspiration. The intention was to evaluate and use certain aspects of the theories to build and create the framework specifically for SMEs to initiate and aid implementation.

One of the initial change models explored was Lewin's change model, which follows a simplified three step approach. The first step is unfreezing of existing processes and realizing what needs to change, followed by the second step of changing while involving people in the process and lastly refreezing the processes and providing support by having resources readily available for team members or employees to ease the transition (Galli, 2018). Even though it is highly simplified, the aspects of involving people in the process and providing a support in terms of individual and/or knowledge base within or outside the organization is of potential interest when considering changes pertaining to using and adapting to new technologies. However, the

organization needs to be mindful of the size of change they are trying to achieve. Otherwise, it will be challenging to convince the teams to accept the change.

Another change management model explored is the McKinsey 7-S model, which involves transforming the organization from the current position to the new position (Galli, 2018). The seven aspects of the change model focus on assessing the strategy of the business, evaluating the existing organizational structure which identifies and defines the roles, responsibilities, and accountability relationships; analyzing existing systems, which include planning, budgeting, resource allocation systems and information systems, revisiting shared values, style, listing staff involved in the business and lastly assessing skills (Galli, 2018). The interesting aspect of this model is how a firm evaluates the organizational structure by giving attention to defining the roles, responsibility, and accountability for the defined roles.

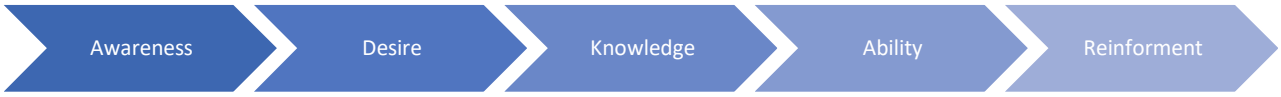


Figure 14: ADKAR model

ADKAR is another change management model used as inspiration for how to persuade people to change. The process involves five stages starting with awareness of change needed along with the degree of change, followed by desire to change in terms of the motivation of the team and its capabilities. Thirdly, knowledge of how the change should be implemented and what the change entails, followed by the ability in terms of skills and mindset. Lastly, reinforcement to maintain and sustain change to increase the likelihood that the change will be continued (Hiatt, 2013).

When considering change, influencing behavior and decision making, the concept of nudge theory was also considered. One of the main aspects of nudge theory is maintain the freedom of choice and defining change through employee's perspective. Presenting change as choice, while

engaging feedback through transparency and openness, results in a momentum for incremental change(Sunstein, 2019).

Keeping the above theories, models and concepts in mind, the following section will dwell with the creation of the change process framework for implementing standards based on the insights gained from the investigation and expert interviews.

6 Change implementation strategy

6.1 Insights from the Interviews

Many interesting insights were gained with regard to a possible solution for increasing awareness and speeding up acceptance based on the size of organizations. When considering implementing standards, Rahul Shah mentioned in the interview that "*organizations should view the implementation of any standards as an organizational change*." As such implementation include a wide range of tasks to be added to the existing ways of working, it is important for the all the members of the organization to be made prepared. In terms of managing and handling change, Ross stated that he thinks "*controlling the change within your own organization, is a much better position to be in than being forced to change*." He also mentioned that "*actually sitting down and deciding that you're going to change, and this is how you're going to do it is a much nicer position to be in rather than three years' time and realizing that you are completely behind, and you can't even tender for a project because you don't have anybody in house with that knowledge base*." This insight brings up an importance aspect of viewing change as a long-term process that involves planned incremental change.

In terms of how organizations are currently implementing the insights from the interview are as follows

- Change management strategies, hiring/ assigning innovation manager to keep an overview about the innovation processes with the organization.

- Wardley mapping model for awareness and implementation, a strategy and technique to help understand what to build, what to buy and where technology ecosystem is currently at to create situational awareness. The strategy focuses on using Sun Tzu's Five Factors: purpose, landscape, climate, doctrine, and leadership.
- Approach for implementation vs approach for development
    - Aggregate with associations – companies can be part for industry association to gain insights for development and implementation.
    - Identify and bid for projects that have government mandate – identify niche environment within the industry to have a competitive advantage.
    - Hire an In-house implementor – for handholding to implement – good to go after initial training and implementation period.
    - Simplification of products/services, especially as start-ups – use agile methods and plug and play approach to make the product/service user friendly and easily accessible.

Another insight gained during the interview with Rahul Shah on the possible direction to help organizations to strategize and realized what is necessary for change is the 5-dimensional strategic implementation plan which can be scaled to any size.

- Step 1: WHY do you want to do this?
    - What is the purpose?
    - Identify drivers for implementation- internal drivers like aspirations, improvements etc. external drivers like government or client mandate, overall industry trend
- Step 2: WHAT info/resources organization needs – hardware, software, manpower
- Step 3: HOW- what are the procedures and protocols needed
- Step 4: WHEN- project implementation of technology, specifying which phase would be most beneficial, role in industry
- Step 5: WHO needs to be involved, roles and responsibilities, training of employees

Through the various insights from the interviews about implementation strategies and differences between the large organization and small and medium size firms; the perspective for creating an incremental change process shifted to creating a toolbox for the small and medium-size firms to aid them with the implementation of standards, and the respective change process the firms will have to carry out to implementation.

6.2 Approach for incremental change process

With the insights gathered from investigation and interviews, addressing the need for standardization became the central aspect to influence the direction for proposing an implementation framework for SMEs. Focusing on standardization would address the issues of interoperability and misinterpretation of data, aid users to use the data more efficiently and effectively as per relevance, and reuse data, ultimately leading businesses to save time, effort, and money in the long run.

To create the framework for implementing standardization, it is prudent to address the other underlying pain points and issues mentioned in section 2.2. Issues like how and where businesses can start the process of implementation, what to prioritize and realize which technologies trends are relevant to their own businesses. Secondary issues like lack of clarity in understanding, who does what, when and how and lastly, what are everyone supposed to do with the technologies and how to identify missing capabilities with the business.

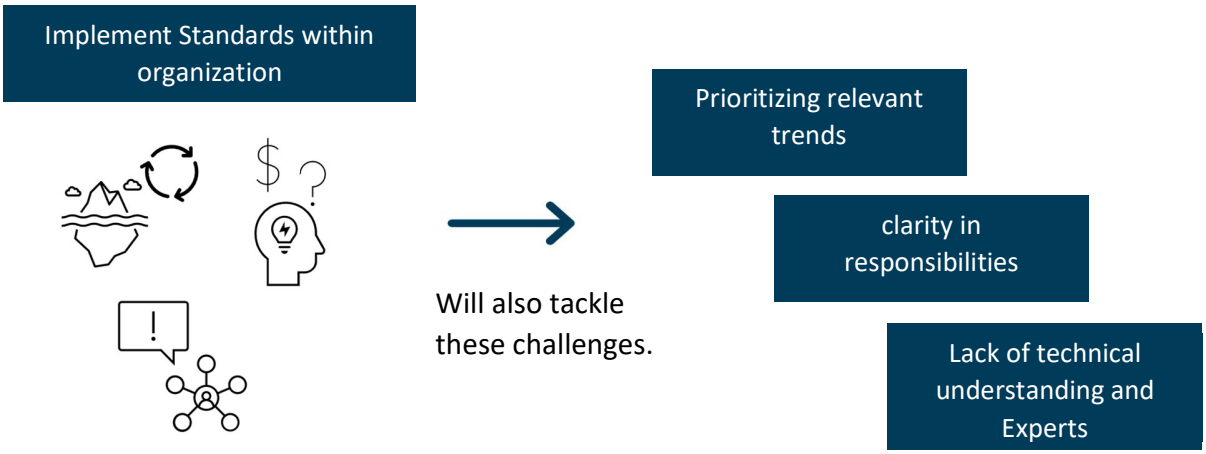


Figure 15: Issues to be tackle while implementing standards

At a glance, these issues seem interrelated, and the above figure expresses the thought process to how all the issues be tackled within an organization in a systematic and incremental way without completely disrupting the existing processes and tasks that are taking place already.

Keeping all the above structure of incremental change approach in mind and using academic and practical inspirations, a change process framework is proposed specifically to aid SMEs to implement agile way of identifying missing capabilities. The aim of the framework is to help businesses align their existing capabilities with what is missing for a structured and informed decision-making regarding implementing standards.

The framework focuses on the involvement of team members from all organization levels at specific stages. As indicated from the figure below, the initial step one involves top management gauging need for incremental change, followed by step two where top management and team leaders from all departments defining tasks needed to implement standards. Step three is to involve all team members for clarity in task and role, including a responsibility matrix (which will be dwelt in detail in the upcoming section). Step four involves top management and team leaders identifying missing capabilities and making decisions based on step three. Last stage is accessing key performance indicators to evaluate if the incremental change has been successful and what needs to be improved on. The following section will go in detail with the processes, stages and degree of involvement comprised within the five phases mentioned below.

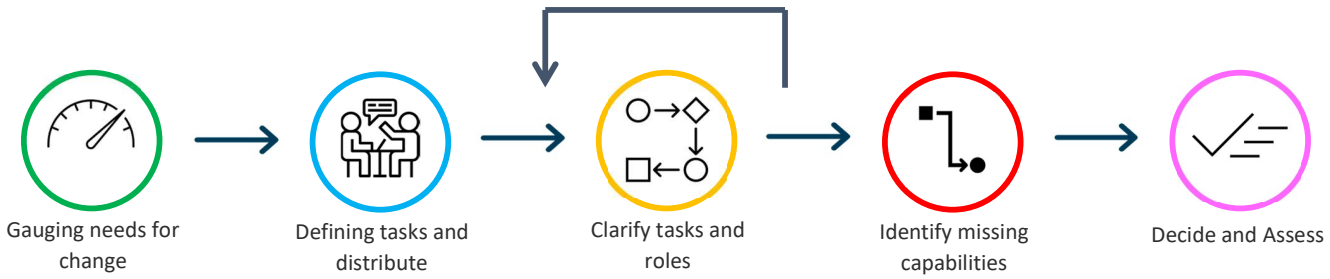


Figure 16: Framework for change process

6.3 Storyboard for proposed framework

6.3.1 Gauging needs for change.

A detailed Storyboard exercise was conducted to dive in to express how all the processes and people interact within each phase and how the responsibility Matrix (RASCI) would come into play to aid with the structured yet agile way of identifying missing capabilities. As sketched in the storyboard below, the first stage is the awareness stage. Through external forces like technology trends, new client/project requirement or to gain new and interesting projects; and internal forces like innovation savvy team members proposing solution/service to use for a business case, the top management initiates the process of evaluating what needs to be implemented for the business to thrive and how can the business get more relevant projects/commissions.

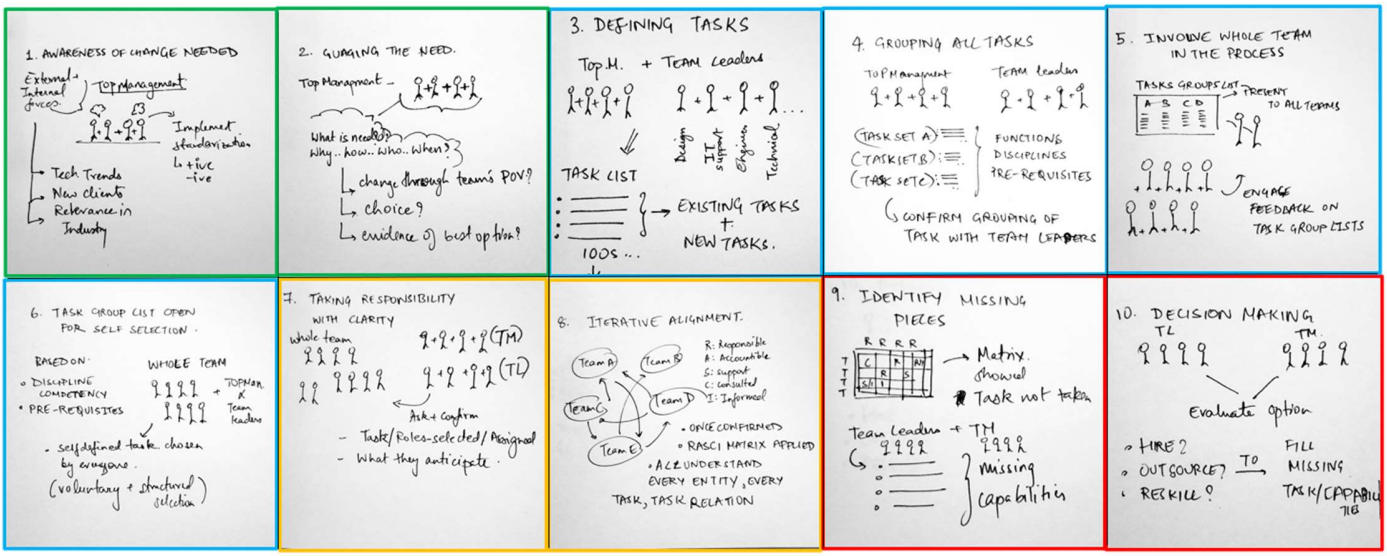


Figure 17: Storyboard for proposed framework

Stage two is where the top management gauges the need for change for the business by exercising the five-dimensional strategic implementation thought process –the why (purpose and drivers for implementation), the what (organizational needs -hardware, software, and manpower), the how (protocols and procedures to be added to the existing), who (roles and responsibilities) and when (level of involvement and timing of implementation with regards to industry trends). It is also prudent at this stage that they gather substantial evidence for why the

change is the best option they have, to persuade the whole team to get on board with the change later. It would be easier if they consider the change through the team's point of view and present the change as a choice. This will have a different psychological effect on how everyone in the organization perceives change and ease everyone's transition through the change.

6.3.2 Defining task and distribute.

Once the top management has evaluated the needs, it involves the team leaders from different departments within the business (for example design, engineering, technical, IT support) in stage three to define tasks that needed to be done, if the change needs to be implemented in a systematic way. The people involved in this stage compile the tasks that are already existing with the new tasks that need to be added to achieve the goal established in the first two stages.

After all the tasks have been defined, stage four is where the top management and the team leaders group the tasks based on the function, disciplines and pre-requisites needed for the defined tasks. The input and confirmation of the team leaders is necessary at this stage so that the task group are ready to be presented to the whole team. Keeping in mind that this is an agile and flexible process, it is necessary for one individual or a team within the company who have a holistic view of the company to take the full responsibility to guide the teams within the organization through the implementation of new processes and relevant technologies. In other words, one individual among the team leaders is appointed innovation/change process manager. Depending on the size and manpower of the organizations and its capacity, either one person or a team can be made responsible for overseeing and evaluating implementation.

At stage five, all team members are introduced to change that is going to be implemented with the support of the thought process the top management has established in the first two stages. They are also given the opportunity to be involved in the process.

A sub-stage within stage five is engaging feedback from the team members, which will involve only the collective team leaders and the team members. The feedback received will then be incorporated depending on the quality of the feedback and the team leaders.

Stage six continues with the involvement of the whole team, where the confirmed task group are open for self-selection, the self-defined tasks are voluntarily and structurally (keeping in mind the function and pre-requisites) chosen by everyone. This stage is essential and unique as one would get a glance at how some team members could have a combination of skills that could be useful in tasks that are quite different from what they are already doing. At this stage, the team members have the opportunity to voluntarily take in tasks that they believe they are capable of doing on top of their existing responsibilities.

6.3.3 Clarify tasks and roles.

The next stage is where the team leaders confirm the self-chosen tasks with the team members, what they anticipate from the tasks they have selected and the roles that are assigned. Once confirmed, they move to stage eight and conduct iterative session within the defined task groups so that everyone understands all the entities that are in play, every task and task relations. To aid this process, the application of the RASCI responsibility matrix is prudent to get a structured outlook and clarity on all task groups. The matrix involves the aspects of responsible, accountable. support, consulted and informed. Responsible is the individual who completes the task, and accountable is the individual who is answerable for the result of the task performed, he/she also oversees the progress of completion. Support is individual/group who assist the one responsible during the process of implementation. Consulted is the individual who is consulted on how to get the task done effectively, and informed is the individual who is kept updated regarding the progress and development of implementation of the task (Reeves, 2019). Once they are filled and sorted based on the tasks and roles chosen in the previous stage, the matrix will indicate the tasks and respective roles that are not taken and accountable for, (an example of RASCI matrix template is mentioned in the Appendix).

6.3.4 Identifying missing capabilities.

Stage nine is where the team leaders and the top management can use the matrix to identify the task and capabilities that are missing within the organization and then use that insight in stage ten to evaluate whether the missing capabilities can be fulfilled. The top management can then

take an informed decision based on the business capacity on whether to hire new personal, outsource the missing tasks or reskill people already in the organization.

6.3.5 Assessing Key Performance Indicators (KPIs).

Once the process has been executed, the top management should assess the process based on key performance indicators (KPI). KPIs to be considered and measured are level of productivity, number of reworks and/or data misinterpretation, quality of data created, transformed and the consistency in the format the data has been internally and externally exchanged, subsequent time and effort saved and employee satisfaction. Keeping in mind that external and internal forces can influence the rate of implementing change within the organization drastically, when it comes to reassessing or recalibrating the direction the organization is pursuing based on evaluation, it would be beneficial for the appointed innovation/change process manager and rest of the team leaders to make sure that they have crystalized and frozen certain core aspects after the initial stages of gauging the needs and defining the tasks needed for change. Moreover, the iterative process that is agile and flexible and the feedback engagement stages are the points go back to during re-assessment and use those stages to their benefit to recalibrate the incremental steps.

6.3.6 Summary

To summarize, the above incremental change process for implementing standards focuses on re-structuring SMEs, based on iterative approach to identify where is the lack of capabilities and potential willingness for reeducation and adding new roles on top of existing ones and using RASCI matrix to have clarity in new defined roles – The result is agile way for creating awareness of all task towards the set change process, clarity for organization to realize what is missing and based on the tasks and capacity: hire /outsource/reskill.

6.4 Use case scenario

As an example, let us assume an AEC consultation firm wants to implement and use ISO 19650, the standard for organizing information about construction works. "*It sets out the concepts and principles for the business processes across the built environment sector in support of management and production of information during the lifecycle of built assets*"(EFCA, 2018)

Starting with gauging the needs – the top management can evaluate the benefits of implementation: lowering risk and reducing financial losses, managing ownership and liability of project data. They can assist KPI like reliable, structured, re-usable form of information, efficiently shared, experiencing less contradiction or misinterpretation of data to measure and assess.

The top management will have to evaluate their position and level of involvement within the whole sphere of the project and its life cycle. The following diagram is a visual representation of the client (appointing party), the main consultants and contractor of the project (lead appointed party) and sub-contractors (appointed party and task teams). The flow of information is generally defined in the contract, and it normally takes the form of sub-contractors exchanging information with the main contactors and consultants and then the main contractor and consultants exchanging information with the client and/or in between each other.

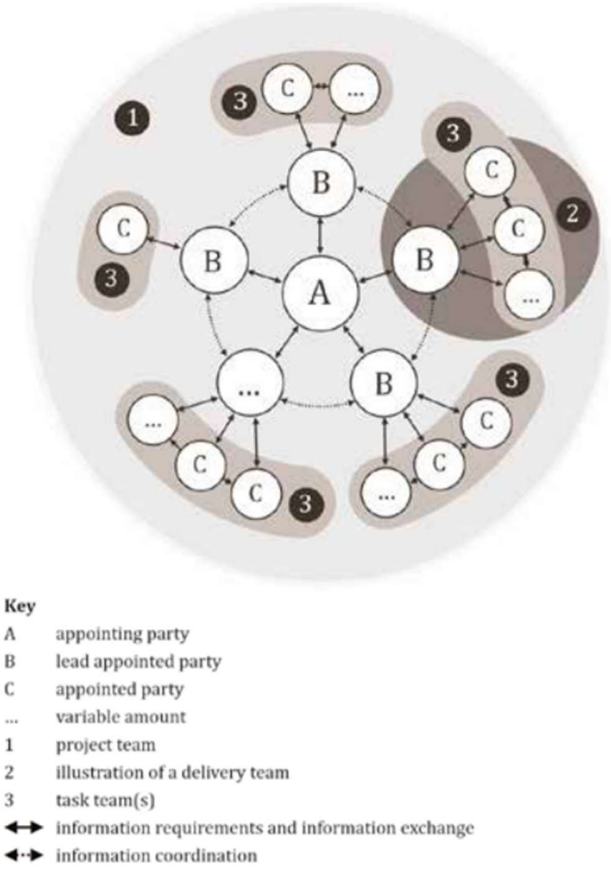


Figure 18: Interfaces between parties and teams for the purpose of information management (EFCA,2018)

Once the position of the company and its scope is clarified, the standards present the structured process of delivering information. The following figure is an example of the delivery process as per the ISO19650 part 2. ISO 19650 - Part 2 explains a set of processes for information delivery in the cycle of design, construction and handover, including those relating to tasks, roles and responsibilities, as well as the identification and assignment of accountable parties for each activity and task (EFCA, 2018). As mentioned in the figure below, the process spans eight consecutive stages between specifying the requirement to the project handover.

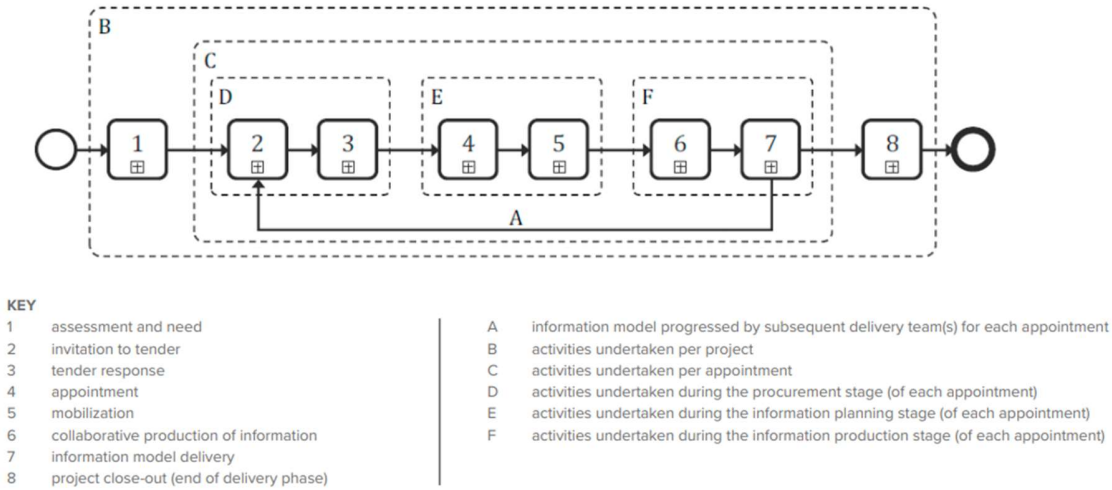
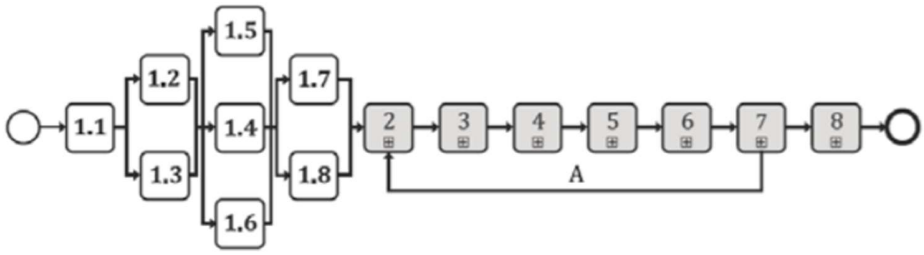


Figure 19: Information delivery process with Stages 1-8, according to ISO19650 – Part 2 (EFCA,2018)

According to the standards, at the phase of defining the task for each of the stages, the process starts from assessment and need, an invitation to tender, tender response, appointment, mobilization, collaborative production of information and project close-out phase. The approach to execute these stages is through an incremental process. The team leaders and top management will have to evaluate and categorize the tasks within each of the stages.

The team leaders will have to make sure they have the technical, hardware and software capacity to carry out establishing a Common Data Environment (CDE), which is a central repository where information regarding the construction project are stored through the project life cycle. They need to make sure they have people in their teams capable of executing and creating documentation, graphical model and non-graphical content in a specific format and also allocate room for task related to it, possibly requested by the client.



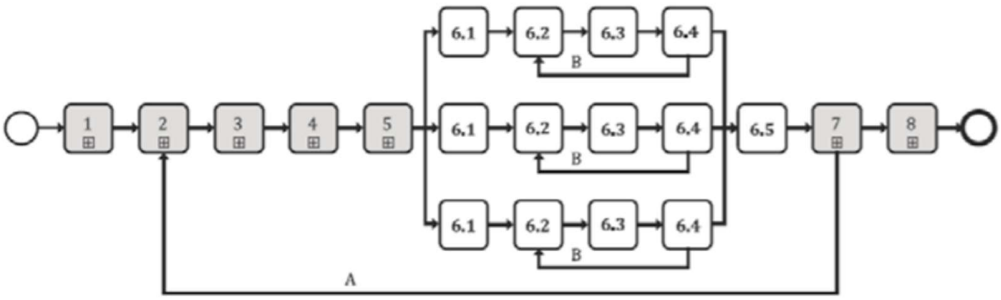
KEY
1.1 appoint individuals to undertake the information management function
1.2 establish the project's information requirements
1.3 establish the project's information delivery milestones
1.4 establish the project's information standard
1.5 establish the project's information production methods and procedures
1.6 establish the project's reference information and shared resources
1.7 establish the project's common data environment
1.8 establish the project's information protocol
A information model progressed by subsequent delivery team(s) for each appointment

NOTE Activities shown in parallel are to highlight that these activities can be undertaken concurrently and apply to all instances

Figure 20: Information delivery Stage 1 – assessment and need, according to ISO 19650 - Part 2 (EFCA,2018)

Example for task list defined by a standard for stage one of information delivery process (EFCA, 2018):

- appoint individuals to undertake the information management function
- establish the project's information requirements
- establish the project's information delivery milestones
- establish the project's information standard
- establish the project's information production methods and procedures
- establish the project's reference information and shared resources
- establish the project's common data environment
- establish the project's information protocol A information model progressed by subsequent delivery team(s) for each appointment



KEY

6.1	check availability of reference information and shared resources
6.2	generate information
6.3	complete quality assurance check
6.4	review information and approve for sharing
6.5	information model review
A	information model progressed by subsequent delivery team(s) for each appointment
B	new information container revision

NOTE 1 Activities shown in parallel highlight the production of information by each task team prior to the information model review.
NOTE 2 The information model review undertaken in 6.5 can be repeated until such time as the information model is ready to be submitted for lead appointed party authorization.

Figure 21: Information delivery Stage 6 – collaborative production of information, according to ISO 19650 - Part 2 (EFCA,2018)

Example of task list defined by a standard for stage six of information delivery process (EFCA, 2018):

- Check availability of reference information and shared resources
- Generate information
- Complete quality assurance check
- Review information and approve for sharing
- Information model review A information model progressed by subsequent delivery team(s) for each appointment B new information container revision

Once all the tasks have been grouped, the team leaders will present the task groups to the team members. Then based on the core competencies and functions, the team members choose the tasks list groups – the team leader will have to allocate one individual who will undertake information management functions within the delivery team. One person will be responsible for project information standards, methods, and procedures, while another will be accountable for establishing the specific project's CDE. Two to three people will take the responsibility of

generating information while a team leader would be chosen to be the person to be kept informed regarding the status for the same.

Once the team leaders have the RASCI matrix filled in with all the tasks and the respective roles at responsible, accountable, support, consulted and informed, they will have clarity on the tasks that have not been fulfilled from the list. For example, if the capability for technical support for a specific stage in the generation of information is missing and there isn't a specific support within the organization, who, for example knows how to work with classification systems, then the top management and team leader can take a call on whether they should hire someone with the required specifics/experience, or outsource it based on the frequency of occurrence or if they have some time in hand and the missing capability is of higher significance and beneficial for the whole team, they can consider reskilling their task teams specific to the missing capability.

The above example of a task list pertaining to ISO 19650 is part of a vast range of tasks to carry out throughout the project life cycle. Hence, it is necessary for the top management and team leaders to view and treat this as an incremental change process and that they are prepared to analyze and evaluate what is needed to execute the standards.

The proposed incremental change process will aid the top management and team leaders to systematically analyze and evaluate the process, the missing capabilities and give leverage to achieve successful adoption of standards within the organization.

6.5 Benefits

One of the main benefits of this approach is that this framework is scalable and adaptable to the needs of the business. This gives room for the top management to define and curate the actions necessary for the change, making sure that the change is not abrupt and with just cause, to ease the organizational transition towards the change.

The process framework can also be reiterated for the purpose of an incremental change process, which gives flexibility and room for improvement with every iteration and better control for the team leaders and top management over the pace of the transition.

The Key performance indicators can provide a primary understanding of the effects of implementing standards to already existing processes which in turn provides a foundation for the top management to navigate the next stages of incremental change.

6.6 Potential challenges

Certain assumptions have been made based on the agility and flexibility of the proposed framework. The evidence based transparent communication of why the change is needed and assurance for room to navigate the change should aid with sense of conservatism and change management difficulties. However, there are chances that in the initial phases of implementing this framework in practice, it may lead to high investment in terms of time and effort, unfavorable cost implications in terms of investing in technologies, and longer time to get used to this approach. It would be interesting to explore potential opportunities to implement the framework and test it in some environments.

7 Testing and Validation

7.1 Interviews

The interviews helped with gaining immensely useful insights that have shaped the investigation, especially to understand the level of changes happening with different spheres within the AEC industry. The insights also guided the investigative perspective to focus on smaller and medium-size companies for the change process framework to implement standards. Keeping the pandemic in mind, it was also a bit challenging to get a large sample of industry experts, so special attention had to be given to gather varied expert opinions from specialized areas within AEC industry. The pool of interviewees ranges from founders of start-ups, project manager, BIM specialist, BIM strategy and standards implementation and software developers.

Due to the nature of the investigation, the data collected during both desk research and talks/interviews with employees/experts are qualitative in nature rather than statistical.

Nonetheless, supporting data gathered through industry wide studies and reports contributed to quantitative data to build the case within the report.

7.2 Feedback and future perspectives

Additional insights were gained through second round of interviews to get validation and feedback on the proposed change process framework. The interviewees liked the concept of looking at the implementation as a change process. As there is no one way of implementing standards, the framework could be used as a toolbox for suggesting agility and flexibility while having structure. The iterative aspect of the process can translate to being implemented to different degrees of change.

Some Potential direction to consider based on the feedback received are considering the drivers for SMEs to change, consider the timeline of such implementation, what is the anticipated time that this process could take within an organization; how can you simplify the process of involving all the team members; possibilities to clarify and dig deeper into how to manage the internal and external forces that could influence a firm to pursue such a change and also the factors that influence the course of incremental change. Further validation and expert opinion will be gained for the proposed framework.

8 Conclusion

Even though, structured information has been around for a while in other domains, it has only recently started to gain popularity within the construction industry. Current trends like digital transformation and technologies from other industries like information technology, are also influencing innovation within the AEC industry. To keep up with digitalization, better and more effective cross-functional collaboration and integration is necessary, which can be achieved through standardizing processes and methods.

Through investigation, many AEC industry-wide issues ranging from issues of interoperability between system-system and human-system to lack of integration between all the stakeholders within the construction project life cycle were brought to attention. Additionally, need for easy accessibility of data, simplification of processes and methods for better understanding, and need for firms to identify and prioritize which technology trends are relevant to their business also became significant to address.

Parallelly, various existing and emerging methods and technologies were researched for better technical understanding. Technologies and structured languages catering to integrate and standardize information exchange among various AEC stakeholders like BIM, IFC, classification systems, structured vocabulary, COBie, linked data and graph databases were dwelt in detail to get clarity on the current level of adoption in the industry.

Through the expert interviews, it was confirmed that implementing standards, would address the mentioned issues while inculcating innovation within the AEC industry. However, the consensus was that the implementation and adoption of technologies and methods for standardizing information exchange would take five to ten years to become technologically developed and mainstream among all types of AEC stakeholders. With insights on the extent to which standards are being implemented among all sizes of AEC stakeholders, it was brought to attention that there are ongoing top-down efforts within the industry to achieve standardization, but not enough bottom-up effort. Hence, special focus was given to how SMEs can start implementing standards within their business processes.

Various existing theoretical models and practical concepts were researched and evaluated to gain inspiration for implementation framework, especially concepts of innovation management, and change management models were quite insightful. The proposed incremental change process framework is a tool kit for SMEs to use as reference for implementation of any scale and kind. It can be re-iterated to the point where the organization has streamlined the intended change within its processes, resulting in innovation as an outcome. As illustrated in the use case scenario, the main idea behind restructuring of organization is evidence based incremental change process, with involvement of all members from different levels within the organization to identify

where are the lack of capabilities and potential willingness for reeducation. Using RASCI matrix to bring clarity for defined tasks and roles, this framework provides a way to prioritize what technology trends to pursue and the respective changes need to be made, more importantly, make structured and informed decisions to fulfill the missing capabilities that will ultimately help the organization to thrive.

For future research, it would be interesting to investigate the potential challenges that can come up with practical implementation of the proposed framework. It would be interesting to see whether challenges and potential flaws like the amount of time invested during the process, possible cost implication and resistance to change could influence the process, and if the agility, flexibility, and iterative aspects of the framework can help overcome these challenges.

The whole investigation turned out to be an exploration for changes that can be made to encourage innovation in organizations, changes that can be implemented to make an organization agile and prepared to thrive in a complex and fragmented ecosystem of the AEC industry. Even though the awareness and adoption of the emerging technologies and methods that aid structured way of exchanging information will take time to become mainstream within the industry; it is leading the AEC industry to have a better and smarter built environment in the future. The proposed framework is only an attempt towards making sure not only the large organizations, but also small and medium sized companies within the AEC industry get the opportunity to keep up with the changes the AEC industry is going through and will be going through in the upcoming years.

9. Bibliography

Balcaitis, R. (2019, June). *Design Thinking models. Stanford d.school*. Retrieved from empathizeit.com: https://empathizeit.com/design-thinking-models-stanford-d-school/

Beetz, J. (2018). Chapter 8 Structured Vocabularies in Construction: Classifications, Taxonomies and Ontologies. In *Building Information Modeling: Technology Foundations and Industry Practice* (pp. 155-165).

BSI. (2021). *bsigroup*. Retrieved from https://www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/

Hiatt, J. M. (2013). Employees Survival Guide to Change: The Complete Guide To Surviving and Thriving During Organizational Change.

Jakob Beetz, A. B. (2018). chapter 6: Process-Based Definition of Model. In *Building Information modeling - Technology Foundations and Industry Practice.*

Pauwels, P. (2018). Linked Data. In *Building Information Modeling: Technology Foundations and Industry Practice* (pp. 181-197).

Process.st. (2017). *change-management-models*. Retrieved from https://www.process.st/change-management-models/

Reeves, S. (2019, September 11). *A Comprehensive Guide To The RACI/RASCI Model*. Retrieved from goodcore.co.uk: https://www.goodcore.co.uk/blog/a-guide-to-the-raci-rasci-model/

Saarela, J. (2020, February). *Graph databases Use Cases (10 Examples)*. Retrieved from Profium: https://www.profium.com/en/blog/graph-database-use-cases/

Schwabe K, D. M. (2018). Chapter 9: COBie: A Specification for the Construction Operations Building Information Exchange. In *Buidling information modeling Technology Foundations and Industry Practice* (pp. 167-171).

Törmä, S. (2013). Semantic linking of building information models. *IEEE Seventh International Conference on Semantic Computing (ICSC).*

Bauer, F. and Kaltenböck, M. (2011) *Linked Open Data: The Essentials. edition mono/monochrom*, *Vienna, Austria*. Available at: https://www.reeep.org/LOD-the-Essentials.pdf.

Berners-Lee, T., Hendler, J. and Lassila, O. (2001) 'The Semantic Web A new form of Web content that is meaningful to computers will unleash a revolution of new possibilities', *Scientific American*, 284(5), pp. 1–5.

Borrmann, A. *et al.* (2018) *Building information modeling: Technology Foundations and Industry Practice*, *Technology for Facility Managers: The Impact of Cutting-Edge Technology on Facility*

Management. doi: 10.1002/9781119572626.ch2.

Box, I. (2014) *The Information Economy: A Study of Five Industries*.

buildingSMART (2020) 'Technical Roadmap buildingSMART: Getting ready for the future', (April), p. 33. Available at: https://www.buildingsmart.org/standards/technical-roadmap/.

Deltek; Clarity (2019) *Engineering Industry Study*.

Dodge Data & Analytics; e-Builder (2019) *Smart Market Brief*.

EFCA (2018) *BIM and ISO 19650 from a project management perspective*.

Egan, J. (2019) 'Distributed CDE using linked data', in *LDAC Conference*.

Galli, B. J. (2018) 'Change Management Models: A Comparative Analysis and Concerns', *IEEE Engineering Management Review*, 46(3), pp. 124–132. doi: 10.1109/EMR.2018.2866860.

Holtzblatt, K. and Beyer, H. (2017a) 'Introduction', *Contextual Design*, pp. 3–29. doi: 10.1016/b978-0-12-800894-2.00001-6.

Holtzblatt, K. and Beyer, H. (2017b) *Principles of Contextual Inquiry*, *Contextual Design*. doi: 10.1016/b978-0-12-800894-2.00003-x.

Holtzblatt, K. and Beyer, H. (2017c) 'Project Planning and Execution', *Contextual Design*, pp. 465–493. doi: 10.1016/b978-0-12-800894-2.00019-3.

ISO (2019) 'BS ISO 56002 : 2019 BSI Standards Publication Innovation management — Innovation management system — Guidance'.

Sunstein, C. R. (2019) 'Nudging: a very short guide', *Business Economics*, 54(2), pp. 127–129. doi: 10.1057/s11369-018-00104-5.

10. Appendix

10.1 Stages of storyboard

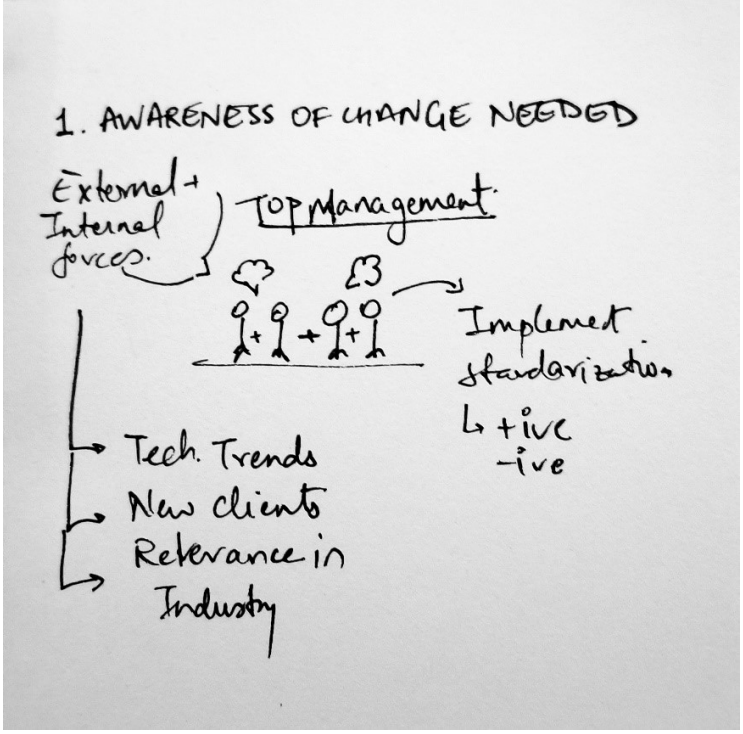


Figure 22: Stage 1, Awareness

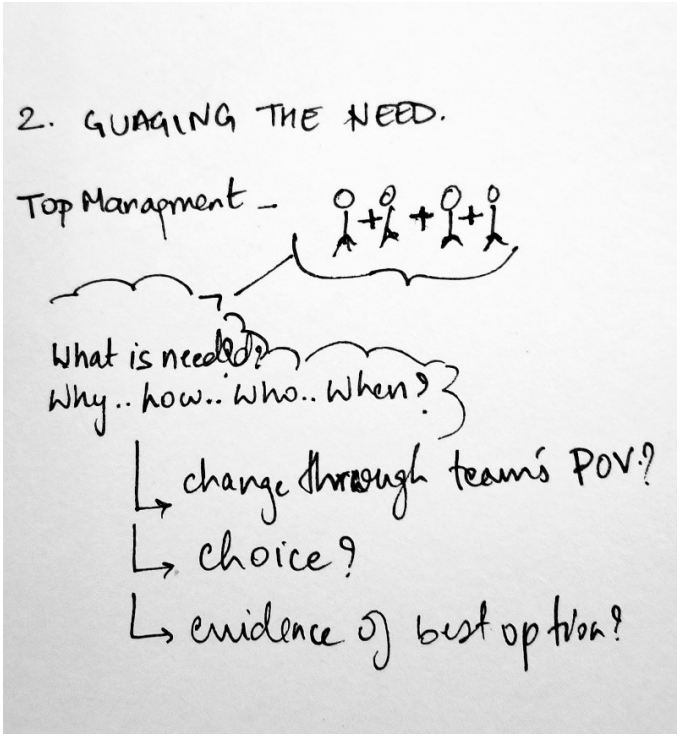


Figure 23: Stage 2, Gauging the need for change

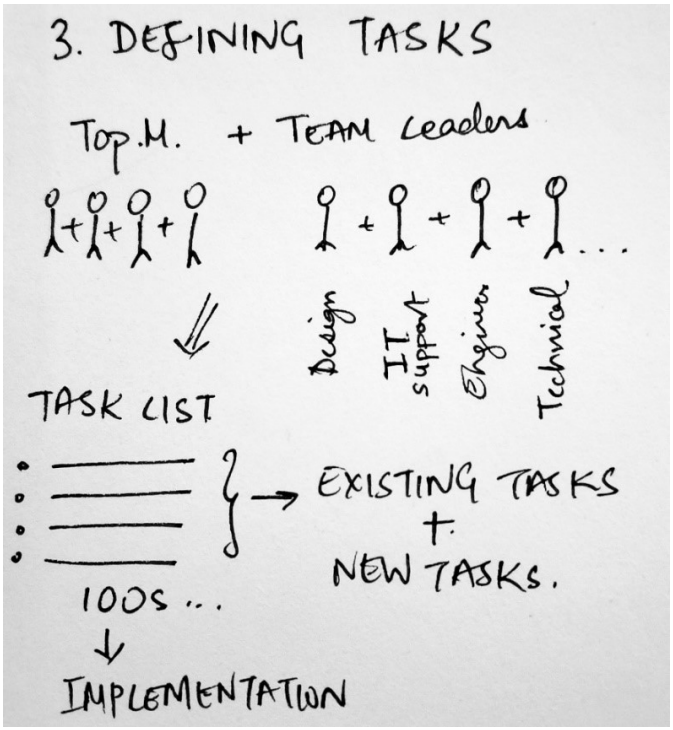


Figure 24: Stage 3, Defining tasks

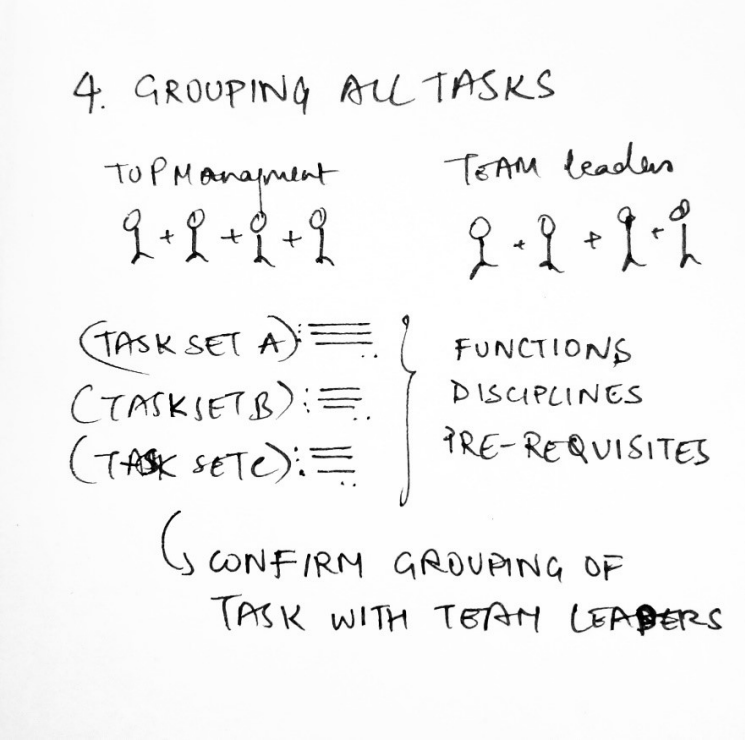


Figure 25: Stage 4, Grouping all tasks

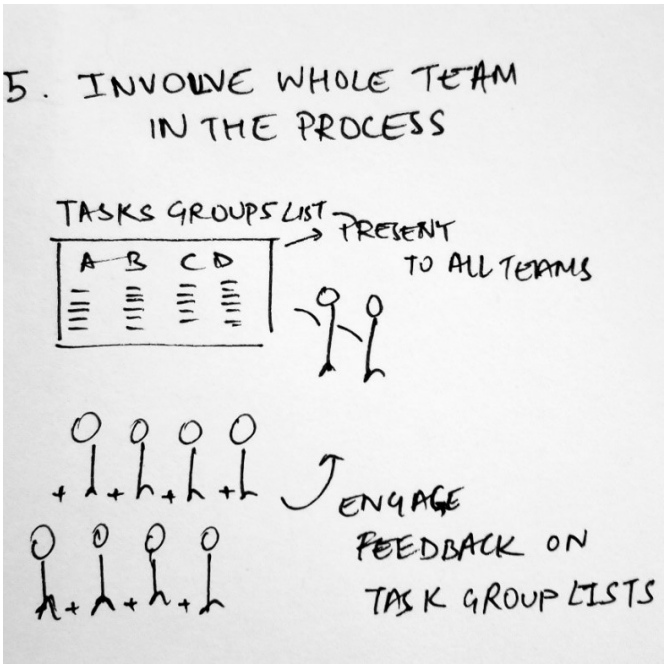


Figure 26: Stage 5, involvement of whole team

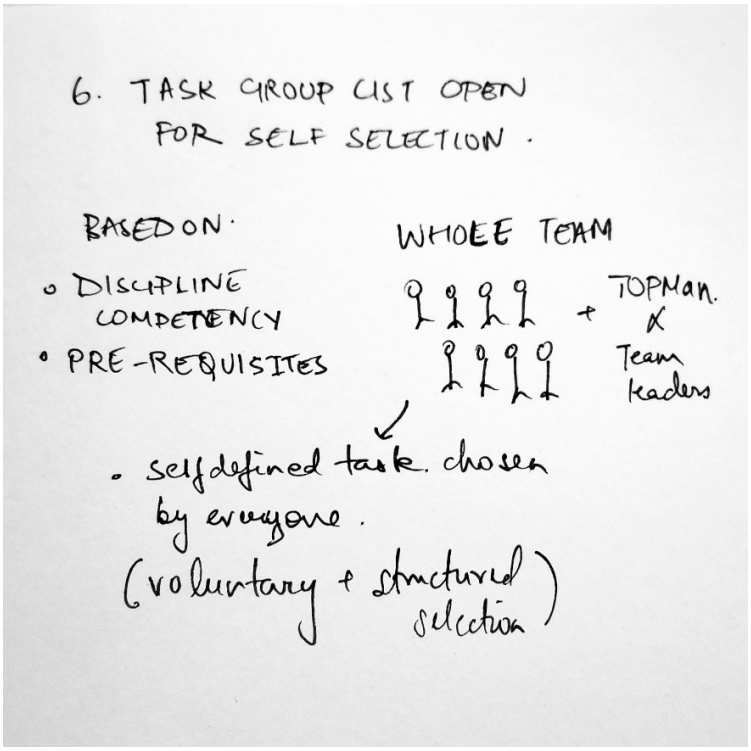


Figure 27: Stage 6, Listing tasks into groups

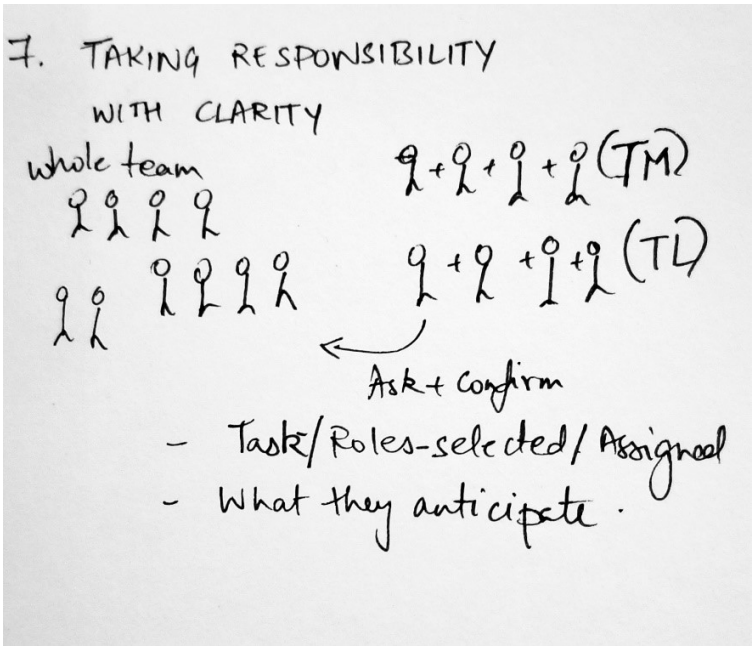


Figure 28: Stage 7, Confirmation of accountability

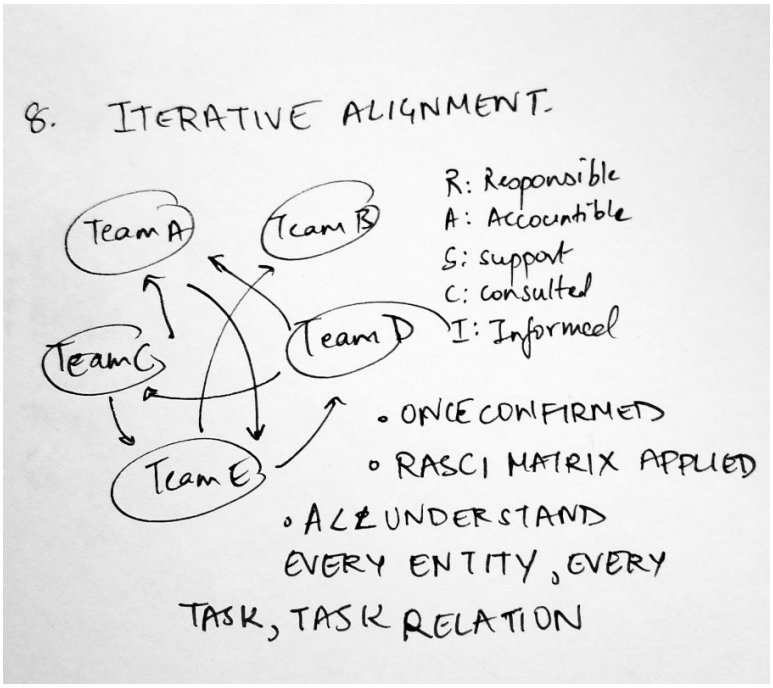


Figure 29: Stage 8, Iterative alignment

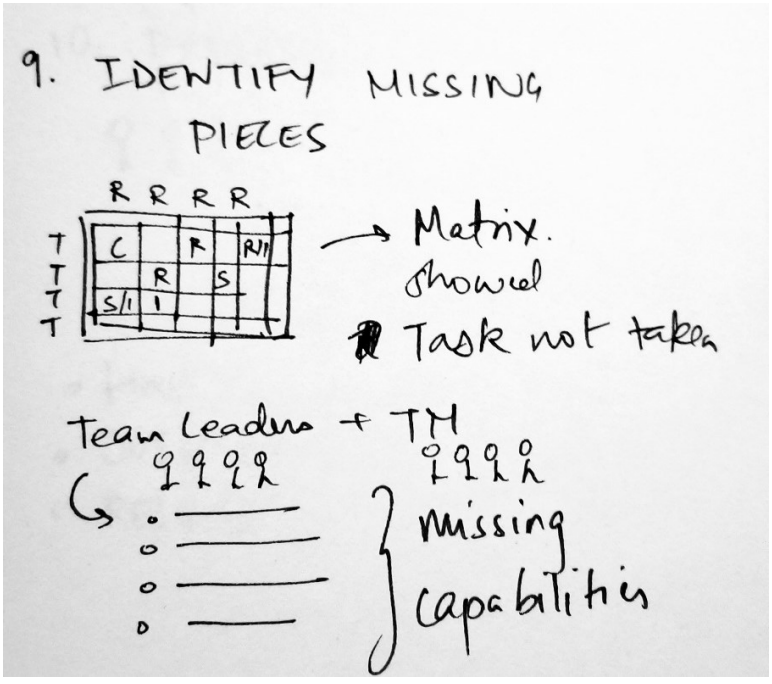


Figure 30: Stage 9, Identifying missing pieces

Task / Role	Role 1	Role 2	Role 3	Role 4	Role 5	Role 6
Task 1	R		C			S
Task 2	R		A	S	C	
Task 3	R	R	I	A		I
Task 4		S	C		R	
Task 5	A	C		I		
Task 6		I	C	C	S	R

Figure 31: RASCI Matrix template to identify missing capabilities (Reeves, 2019)

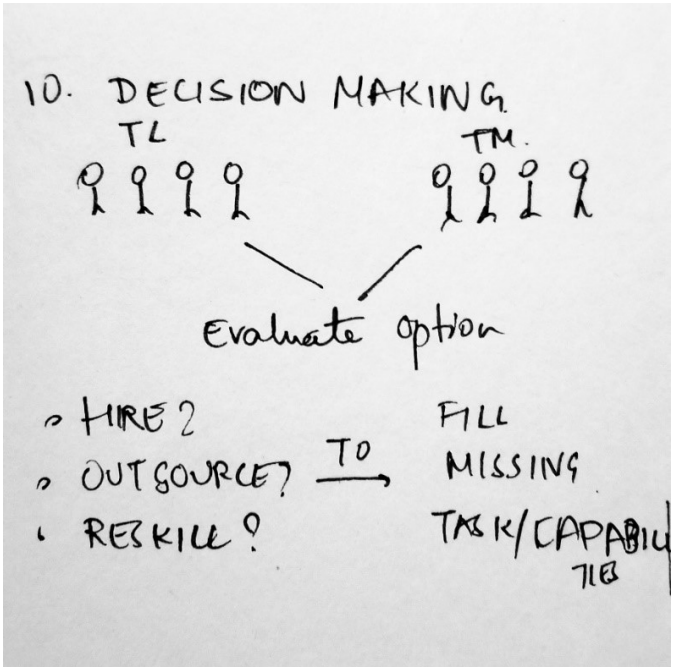


Figure 32: Stage 10, Informed decision making