Influence and Adoption of BIM within the AEC Industry.

A study into how policies, workflows and processes can set the tone towards adoption and implementation of BIM within the AEC industry and how the future of BIM and Data Validation can influence the future of Architects.

Internship Research Paper
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Abstract:

This research paper investigates the topic of *"How policies, workflows and process can set the tone towards adoption and implementation of BIM within the AEC industry and how the future of BIM and Data Validation can influence the future of Architects."*

BIM has become a fundamental aspect of today's AEC Industry. From its conceptual inception in the early 1990's to its widespread adoption and integration in current workflows over the last 20 years. This rapid rate of adoption for BIM within the industry has been accelerated through governmental mandates, client requirements and through its use in larger organizations. This research paper will investigate how the construction sector views the adoption of BIM within the AEC industry and what process and steps are required in order to adopt and implement a digital design work methodology supported using BIM over that of a traditional design work methodology. We will also discuss how current and future roles and workflows of Architects will be defined due to R&D in advancements technological in BIM. For these advancements of innovative solution in BIM will result in a change as to how we define the role of a future Architect to be.

Keywords:
BIM, AEC, Construction Sector, Trends, Adoption, R&D, Technology, Workflow, Future, Influence, Role, Processes, Industry, Innovation, Data, Management, Validation.

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1. Introduction:

Until the 20th Century Architectural & Technical drawings were drawn by trained draughtsmen, who didn't help in designing the form and function of a building but instead were only skilled in drafting detailed plans.[1] Where drafters would help convert the design concepts and sketches of an Architect to technically detailed plans.[1,2] It was only in 1963 when Ivan Edward Sutherland developed SketchPad[3] the first computer-aided design (CAD)[4] solution to help Architects, Designers, Drafters and Engineers understand how computers can help aid in the creation, modification, duplication and analysis of designs. Thereafter through the CAD system, it was easy to adapt and optimize designs.[5] In the early 1980s, the use of CAD in the AEC (Architecture, Engineering and Construction) industry accelerated and enabled for improved efficiency in the time taken for drafting designs. This helped companies to develop their own design templates which they could reuse in upcoming projects.

Early 1990's saw the need within the AEC industry for a data-sharing solution between organizations. Many within the industry wanted to develop a solution that used the internet for project management, data storage and collaboration. Its only in the last 20 years[6] that this need within the industry was filled by BIM (Building Information Modelling). Hence its recognition and widespread adoption is also very recent.

The problem with CAD solutions were that they could not be fully optimized for creating and managing information about building elements, materials and assets that the industry wanted. Hence, using the fundamentals of CAD, the conceptual development of BIM started in 2002 via Autodesk,[7] where information on building objects could be stored and managed in databases for a project. Since the information on these objects were stored in databases frequent changes to the project could take place throughout the built asset life cycle. Thus, BIM solutions such as Revit[8,9] not only enabled the AEC industry to visualize 3D geometrical models and detailed plans of a project, but also helped in the visualization and management of relationships between objects, beyond the level of information seen within CAD solutions such as AutoCAD.[10]

During my Internship Program at Xinaps.BV a company that specialized in creating a cloud-based solution called Verifi3D for Data Validation of BIM Models. I realized that the AEC Industry is very complex. For the industry composes of Architectural, Engineering, Construction and General Contractors in varying sizes. Hence this complex industry consists of multiple disciplines that are fragmented with the adoption and usage of BIM and its technical advancements during a built asset-lifecycle. This fragmentation and inconsistency within the industry with regards to BIM led me in wanting to understand:

A. How bureaucracy and the construction sector view the adoption of BIM within the AEC Industry?
B. The current workflow of organizations within the AEC industry and what steps need to be taken towards the adoption of BIM for projects?
C. How BIM is currently influencing and being used for projects throughout the Building Asset Life Cycle Process?

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[1] Wikipedia Foundation. "History of CAD Software." *Wikipedia*, 14 Jan. 2020, en.wikipedia.org/wiki/History_of_CAD_software.

[2] Quirk, Vanessa. "A Brief History of BIM." *ArchDaily*, 7 Dec. 2012, www.archdaily.com/302490/a-brief-history-of-bim.

[3] Cadazz. "CAD Software - History of CAD CAM." *CAD Software History Sketchpad Ivan Sutherland*, www.cadazz.com/cad-software-Sketchpad.htm.

[4] Paul, Shimonti. "BIM Adoption around the World: How Good Are We?" *Geospatial World*, 28 Dec. 2018, www.geospatialworld.net/article/bim-adoption-around-the-world-how-good-are-we/.

[5] Narayan, K. Lalit., et al. *Computer Aided Design and Manufacturing*. PHI Learning Private Limited, 2013.

[6] Autodesk. "What Is BIM: Building Information Modeling." *Autodesk*, www.autodesk.com/solutions/bim.

[7] Autodesk. "Autodesk Building Industry Solutions - White Paper." *Autodesk BIM White Paper*, 2002, www.laiserin.com/features/bim/autodesk_bim.pdf.

[8] Autodesk. "Transitioning to BIM - Autodesk Revit." *Autodesk Revit Whitepaper*, 2011, images.autodesk.com/adsk/files/transition_to_revit_mep_whitepaper_final.pdf.

[9] Wikipedia Foundation. "Autodesk Revit." *Revit | Wikipedia*, 7 Jan. 2020, en.wikipedia.org/wiki/Autodesk_Revit.

[10] Wikipedia Foundation. "AutoCAD." *Wikipedia*, 28 Jan. 2020, en.wikipedia.org/wiki/AutoCAD.

D. What's the future of BIM within the AEC Industry?
E. Will BIM and its technological advancements change how AEC professionals will work in the future and will it intern change how we perceive and define an Architect to be?
F. How can BIM help in the process of validating building projects for governmental regulatory bodies?

Hence through these sub-research questions, a main research question was formulated to be:

How policies, workflows and processes can set the tone towards adoption and implementation of BIM within the AEC industry and how the future of BIM and Data Validation can influence the future of Architects.

Thus to help answer the main research question along with its sub-research questions, this research paper shall not only take into consideration the insights and knowledge gained through my internship, but I will also be making use of literature material to help me in the writing of this research paper.

2. **Results**:

To help me answer the main research question we need to first investigate the sub-research questions, but before we can do so we need to define what BIM is?

In the case for our research paper, we define BIM (also known as Building Information Modelling), to be the form by which a concept or physical building is represented and managed virtually in a 2D/3D digital modelled environment. Where BIM allows for the storage of information and data that can be visualized in a 2D/3D manner, giving Architects, Engineers and Constructors (AEC) insight and tools for efficient designing, constructing and managing a building along with its infrastructure. In today's digital revolution BIM is used throughout the AEC industry via Architects, Civil Engineers, Constructors, MEP (Mechanical, Electrical and Plumbing) Engineers, Plant and Factory Designers and Structural Engineers.[11]

Hence, BIM is a tool used for producing technical plans and visualizing relationships between objects using 3D geometrical data and information for ease of collaboration in a Common Data Environment (CDE).

A. **Understand how bureaucracy and the construction sector views the adoption of BIM within the AEC Industry?**

On average within the EU (European Union) the construction sector has catered for 18 million jobs that resulted in 9% of the EU's GDP in 2016.[5] While the construction sector is a key part of today's economy, it faces challenges related to labour, efficiency and productivity. For in the construction sector over the last two decades the labour productivity has stagnated and has intern made the construction sector the worst-performing industry in terms of productivity, while other sectors such as manufacturing have seen an increase in productivity from 1% to 3.6% within the same time period.[5] This loss in productivity is many due to the difficulties within the sector pertaining to embracing digital innovation that could help increase productivity while creating new areas of growth.[5] Hence the EU has developed several policies and initiatives to foster and increase the demand for digitalization within the sector. One such example is the EU's policy on Public Procurement (2014) which promotes the use of BIM in construction projects.[12]

[11] Volk, R.; Stengel, J.; Schultmann, F. (2014): Building Information Models (BIM) for existing buildings – literature review and future needs - Automation in Construction 38, pp.109-127, DOI: 10.1016/j.autcon.2013.10.023.

[12] Commission, European. "Building Information Modelling in the EU Construction Sector." European Construction Sector Observatory, Mar. 2019, ec.europa.eu/docsroom/documents/34518/attachments/1/translations/en/renditions/native.

Since BIM is a collaborative way of working which allows for efficient methods of design, delivery and maintenance of building assets,[13] it provides all involved stakeholder with a digital representation of a building and its characteristics throughout the Building Asset Lifecycle.[6] This intern creates for a single source of truth that can seemly be shared between all involved stakeholders, thus preventing loss of information or miscommunication errors during the differing project phases carried out by various sub-contractors or disciplines within an organization.[14]

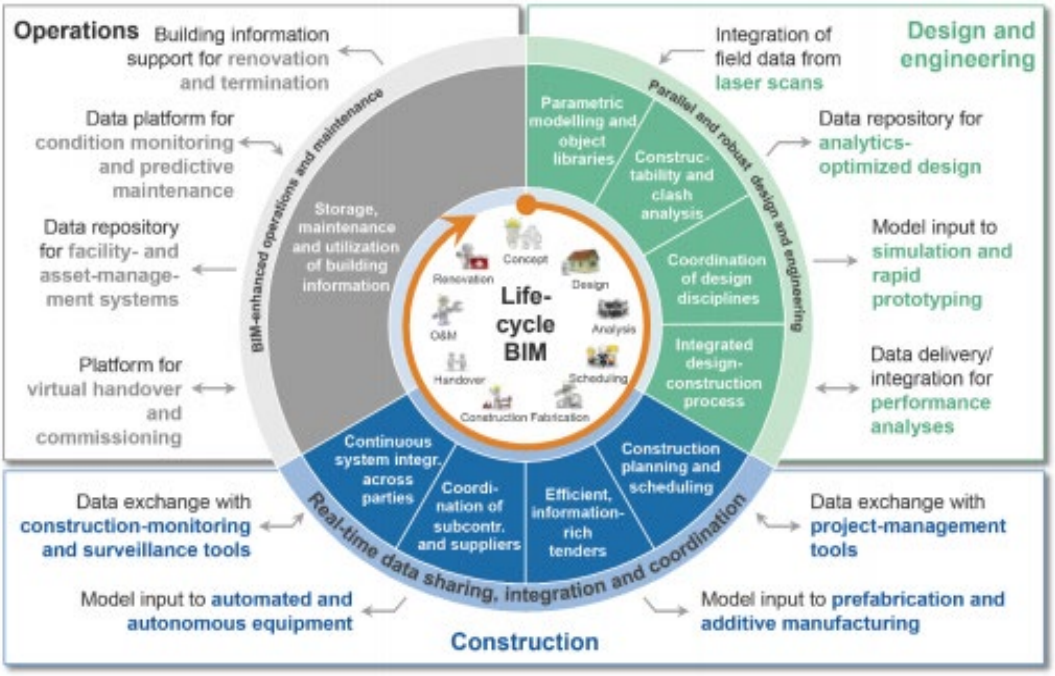


Figure 1: Illustrates the usage of BIM during the Built Asset Life-Cycle Process for thr various sectors of Design and Engineering, Construction and Operation [15]

The BIM market within the EU is valued at 1.8 billion euros as of 2016 and is predicted to grow by 13% by 2023.[16] This growth within the construction sector is driven by the following factors:

I. Increased demand for Urban Development, with growing pressure on sustainability and efficient management of resources.

II. Increased support from Government and Regulatory bodies for various policies and initiatives that help create increased awareness and adoption of BIM in Organizations for projects.

In the EU 29% of construction firms use BIM whereas 61% still haven't made the digital transition from CAD solutions to a BIM environment.[17] This is many due to the fragmented usage of BIM within the AEC industry where BIM is commonly applied for large-scale residential, urban development and infrastructure projects. Within this fragmentation usage

[13] BSI Group. Little Book of BIM 2019 Edition. 2019, www.bsigroup.com/globalassets/localfiles/fr-fr/construction/bim/bsi-little-book-of-bim.pdf.

[14] McGraw Hill Construction "The Business Value of BIM for Owners." Business_Value_of_BIM_for_Owners_SMR_(2014).Pdf, 2014, i2sl.org/elibrary/documents/Business_Value_of_BIM_for_Owners_SMR_(2014).pdf .

[15] Commission, European. "Building Information Modelling (BIM) Standardization ." jrc109656_bim.Standardization.pdf, 2017, publications.jrc.ec.europa.eu/repository/bitstream/JRC109656/jrc109656_bim.standardization.pdf.

[16] NBS. "National BIM Report 2019." NBS, 17 May 2019, www.thenbs.com/knowledge/national-bim-report-2019.

[17] Wood, Laura. "Europe Building Information Modeling Market (2017-2023): Emphasis to Reduce Construction Failure & Operational Costs - Research and Markets." Business Wire, 28 Dec. 2017, www.businesswire.com/news/home/20171228005373/en/Europe-Building-Information-Modeling-Market-2017-2023-Emphasis.

of BIM is mainly seen in the Architecture, Design and Construction phase while limited usage is seen during the operational to maintenance phase of the building asset life cycle.[18] It is also seen that the implementation and adoption of BIM are influenced by the market structure, where the size of the company plays a key role.

For the implementation of BIM is led by large companies that invest in the digitalization of current processes and seek innovative solutions to help make projects more efficient. While small-medium enterprises (SME's) tend to follow with limited experience due to push from large organizations or governmental and regulatory policies. Within the industry, it is seen that 85% of Large vs. 71% SME's of Engineering companies use BIM and 81% of Large vs. 54% SME's of General Contractors use BIM.[5]
This is partly due to larger companies:

I. Having more (financial and labour) resources to implement the widespread usage of BIM in their organization than SME's.

II. Conducting larger and more complex projects that require strong coordination between various stakeholders hence making the use of BIM more flexible while using a CDE and data-standardization processes.

In 2007, Denmark placed a law whereby the usage of BIM was mandatory during procurement of labour and commissioning of upcoming projects. This led to a government-led study where it was seen that 84% of companies believing that BIM is a value-added generative for the construction site, 79% believe that BIM is about creating a collaborative network across all involved stakeholders and 31% believe that BIM is a necessity for creating a sustainable environment.[5, 12]

In 2015, France set-up a similar policy whereby it planned to introduce digital transformation within the building industry (PTNB). This policy lead to a 38% increase in BIM adoption by 2017 while awareness among business this rose from 22% in 2016 to 35%. In addition, this led to 26% of project-owners requiring BIM for construction projects and only 12% that only required a 3D model.[5, 19]

Hence the implementation of government and regulatory lead policies have a big impact on the implementation and awareness of BIM. Although in some case even if policies exist the lack of knowledge and expertise can become a barrier towards to adoption of BIM and can instead result in more challenges than solutions.

B. **Understand the current workflow of on within the AEC industry and what steps need to be taken towards the adoption of BIM for projects?**

To help me answer this question I will not only have to take into consideration my internship experience as a Project Owner and BIM Consultant at Xinaps but will also require the insight gained through reading various literature.

i. **AURP**: Are an *Architectural/Technical Design and Construction* firm that provides designs and technical plans and drawings for buildings and infrastructural projects.[20] At AURP designs, plans and technical drawings are created within the firm. These designs are created in the context of the project requirements as provided by the client. Once the project requirement is understood the project is split up based upon the various expertise it requires. Members from each expertise communicate with each other over issues and work on central or detached parts of a BIM model. Once the individual departments have finalized their designs this is then translated to one

[18] Boston Consulting Group. "Digital in Engineering and Construction." Building Information Modeling, 2016, www.bcg.com/industries/engineered-products-infrastructure/digital-engineering-construction.aspx.

[19] SENER, S. M. Building Information Modelling (Bim) in Design, Construction and Operations Ii. 2017th ed., vol. 169, WIT Press, 2017.

[20] ARUP Group. "Our Firm." *Arup*, www.arup.com/our-firm.

central BIM model. It is then checked for code compliance and data quality, where based upon the results the project will be sent to government regulators for approval.

ii. **BuroHappold Engineering:** Is an *Engineering* Consultancy, Design, Planning, Project Management and Consulting Service that focus on Buildings, Infrastructure and Sustainable Projects.[21] For them, BIM is essential tool that helps them to understand the ins and outs of a project, as the workflow is based upon the digital design methodology of incorporating BIM. For them, a project starts off at an Architectural Firm or Design Bureau which provides them with BIM files. These files are then broken up and distributed amongst the various divisions (such as: Acoustics, BIM & Data Management, Fire Engineering, Façade Engineering, People Movement, etc...)[22] present within the company. Each of these divisions within the company then checks the building in terms of regulatory and project compliance along with its structural and building physics aspects. If there are any problems found with an aspect of a building or the building as a whole it is then sent back to the client (the Architectural Firm or Design Bureau) for revision and hence the cycle continues for them till they ensure that the project can go to the next stage within the built-asset lifecycle.

iii. **Swinerton:** Is a *Construction* company that is mainly focused on Commercial Offices, Rental Units, Residential Units, Hospitals, Healthcare Facilities, Educational Facilities, Energy and Environmental Sectors.[23] It also provides consultation in BIM, Sustainability and Project Management.[24] For them, BIM is a tool which can be used for data validation in the stages before pre-construction. From checking the project requirements easily in the design phase to performing simulations and checks in the fields of MEP and Structural Engineering. BIM is seen as a mandatory tool for them where their workflow is centred around it. At Swinerton, the BIM models are either provided for by the Architectural Design Bureau or by an Architectural Design team within the firm. Since their work is focused around the BIM model, they make sure that the project is code compliant and meets the project standards.

iv. **ENGIE**: Is a *Services and Energy* company that proves building physics solutions for the Mechanical, Engineering and Plumbing (MEP) industry.[25] At Engie, their workflow is such where they get an MEP design requirement from a client and then design out a specific MEP system for the building in accordance with project and regulatory requirements. As the MEP system is being sketched out and checked to see if it meets the project's requirements it is simultaneously designed within the BIM project. Through the aid of this BIM file simulations and checks are performed to validate the data and ensure that the MEP systems work correctly.

v. **HFB**: Is a BIM Agency that creates 3D (BIM) visualizations of a project. They do so by consulting with clients to understand their requirements, to which they make a centralized BIM model. During the process of creating BIM Models, they constantly share their insight and communicate with various contractors and design bureaus to ensure that the model meets the client's requirements. They also make use of data validation tools to check the BIM model against project requirements.

As seen from the above examples the adoption and implementation of BIM is very centric to the successful completion of complex projects. This is because BIM can create a collaborative environment throughout the building asset life cycle and allows for integration within an industry, which is currently plagued by fragmentation.[26] Another advantage of BIM is that it enhances knowledge sharing, increases productivity, and creates solutions regarding project

[21] BuroHappold Engineering. "About Us." *BuroHappold Engineering*, www.burohappold.com/about/.

[22] BuroHappold Engineering. "What We Do." *BuroHappold Engineering*, www.burohappold.com/what-we-do/.

[23] Swinerton. "Markets." *Swinerton*, swinerton.com/markets/.

[24] Swinerton. "About." *Swinerton*, swinerton.com/about/.

[25] "Engie." *Engie - Wikipedia*, 24 Jan. 2020, en.wikipedia.org/wiki/Engie.

[26] *Rivera, Muñoz-La, et al. "Methodology for Building Information Modeling (BIM) Implementation in Structural Engineering Companies (SECs)." Advances in Civil Engineering, Hindawi, 21 Feb. 2019, www.hindawi.com/journals/ace/2019/8452461/.*

coordination and management. Yet another advantage in the adoption of BIM within the workflow is its ability to make changes regarding the cost VS. the traditional methods.

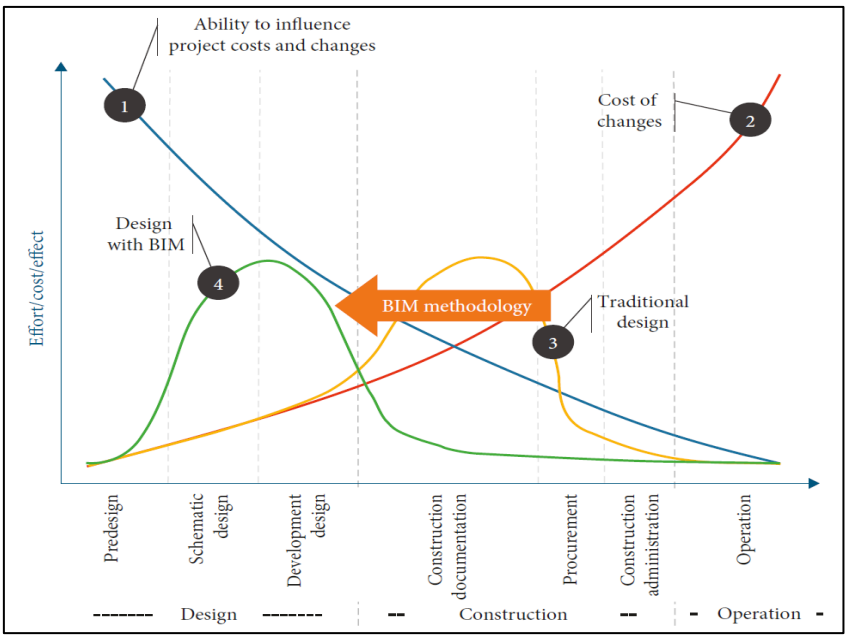


Figure 2: Illustrates the cost of implementing changes over various phases of the built asset life cycle, when comparing traditional over BIM design methodologies. [26]

So how does an organization approach BIM and adopt its methodology and workflow for a project? From the "BIM Handbook",[27] and the "Project Execution Planning Guide"[28] we see that there are varying stages for the implementation of BIM within a workflow. For it is seen that before a company can implement a BIM workflow within their organization, they first need to recognize what their approach, objectives and expectations are, and what they wish to achieve when incorporating BIM within their organization. Hence the identification of roles, teams, functional structure, planning, speed of implementation and training along with the aligning the goals for management and staff will be critical.[19]

Therefore, when analysing a research paper on "Methodology for Building Information Modelling (BIM) Implementation in Structural Engineering Companies (SECs)"[19] we see that a detailed step-by-step program (as seen below) is required for an organization to shift from a traditional design work methodology to that where they can adopt and implement BIM to help support a digital design methodology.

I. **Business Analysis & Diagnosis:** How does the organization work and does it have the resources to meet its required expectations for projects?

II. **General Information**: On the organization, its size, functions and management.

III. **Focus & Expectations of the Company**: Is the implementation plan aligned with the company's vision and objects that it wishes to achieve through the implementation of BIM. Hence within this phase, the organization should define a clear vision, understand the target market for projects and understand the purpose for the implementation.

[27] Eastman, Charles M. *BIM Handbook: a Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*. Wiley, 2012.

[28] Messner, J., Anumba, C., Dubler, C., Goodman, S., Kasprzak, C., Kreider, R., Leicht, R., Saluja, C., and Zikic, N. (2019). BIM Project Execution Planning Guide, Version 2.2. Computer Integrated Construction Research Program, The Pennsylvania State University, University Park, PA, USA, August, Available at http://bim.psu.edu.

IV. **Evaluation of Current Processes**: Understand the available resources (labour, technological and physical space). Hence it is important to understand the available investment/budget for the implementation and reflect upon the current workflows and processes.

V. **Analysis & Understanding of BIM Objectives**: The organization report's its current deliverables while trying to align with BIM against current indicators where the Traditional Design Drafting Process is understood. Thus, the organization can develop a regulatory, data-standard and quality control process to which the Design with BIM Process needs to align against. Therefore, the organization must develop a framework to optimize the currently available resources while achieving the set goals. Further, the framework should indicate goals that need to be achieved in the short, medium and long run.

VI. **Requirements for Adoption of BIM**: Resource allocation for training, planning, organizational restructure, BIM acquisition, Technological Requirements etc. need to be considered.

VII. **Team Roles:** BIM roles, responsibilities and functional requirements of each member within the team need to be specified. Hence the following roles need to be defined within the team:

a. **BIM Leader**: Is responsible for the successful implementation of BIM within the organization, they are also a key player in defining protocols, guidelines and developing the BEP (BIM Execution Plan) plan. Hence, they must have a wholesome knowledge of various BIM solutions while seeking out new digitalization techniques to help increase the productivity and efficiency of the organization.

b. **BIM Reviewer**: Is responsible for the verification of the BIM project based upon technical guidelines, set requirements, organizational protocols and local regulatory standards.

c. **BIM Coordinator**: Is responsible for validating the BIM project and its coordination. They are the single point of contact for various other modules, specialists and must see that they comply with the BEP plan while ensuring that BIM standards and mandates are met.

d. **BIM Modular**: Is responsible for the development of a part of the whole BIM project while ensuring that the information linked to each element is correct. Such that when multiple moulders work on the same project, they can communicate via the BIM model with the Coordinator to ensure that no mistakes or miscommunication errors made.

e. **BIM Project Engineer**: Is responsible for performing modelling analysis on the BIM model. Wherein a large organization it is seen that this role is very specific to an aspect such as: Structural, Acoustics, etc. Analysis of the Model. Project Engineers always correspond with the modular, the coordinator and various involved third parties (such as design bureaus) to ensure that the BIM model can be built as per design.

In most cases, it is better to have their roles as generic as possible when applicable, as this would enable the team to be flexible and adapt to unpredicted challenges.

VIII. **Developing Workflows**: An ideal work methodology is set up for communicating and managing documentation and BIM models (that includes version), to help reduce mistakes and increase production efficiency. An example of an ideal BIM workflow for a project can be seen below including the steps taken by each involved party.

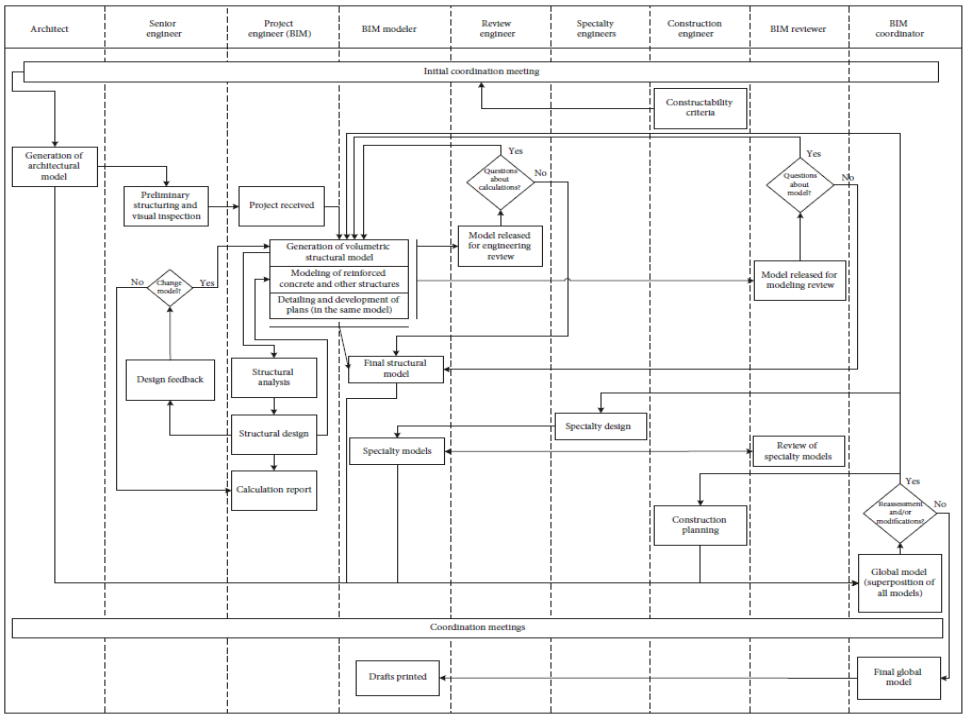


Figure 3: Illustrates an example of an ideal BIM workflow for a project within an organization.[19]

Form this we see that the workflow starts at the Architect who generates an architectural model or impression of the building or project. This model is then transferred to the Senior Engineer who conducts a preliminary structural and visual inspection of the model. The Senior Engineer then transfers the project to the BIM Project Engineer who performs (structural, thermal, acoustics etc.) analysis on the model. This includes making modifications to the design where seen fit and creates a report of the calculated analysis of the project. Once done the project is passed on to the BIM Modeler who created the BIM model of the project and includes all relevant information per building element. Once done the model is reviewed by the Review Engineer who also goes through the various analytical studies to ensure that the model complies with the project guidelines. Once reviewed any specific designs are made by the Specialty Engineer and are superimposed upon the BIM project. After this the Construction Engineer checks the BIM Project against the Constructability Criteria. A BIM Reviewer then checks the project and reviews the superimposed speciality designs that were incorporated. Finally, the BIM Coordinator does a final assessment of the project check all models that have been superimposed within the project and along with the Construction Engineer conducts the construction planning. Once this is done the final model is approved and is given to the General Contractor who will then construct the building as per the approved model. During this whole process, various Coordination Meetings take place via inter-disciplinary teams and experts to ensure the project success by constantly communicating with each other around the BIM project to prevent errors and miscommunications.

IX. **Defining BIM Protocols:** Contains a set of regulatory frameworks, standards as defined by the organization and validation points to which the BIM project should comply towards. Where the protocol must comply and align itself with the BEP plan and implement guidelines for data standardization within the project. Where the protocol can be adapted to the latest regulatory or technological changes. This within the protocol the following must be defined:

a. **Responsibility Matrix**: Defines who has the authorization within the team to make modifications to the BIM Project and what the responsibilities are of

each member within the project. Hence PAS 1192-2[29] is used to define the modelling or information creation throughout the project lifecycle.

b. **Project Development & Workflow**: Defines what documents need to be delivered during the various phases of the project. Including documentation on the planned workflow between internal and external professionals.

c. **General Terms & Guidelines**: Defines the general aspect of various deliverables that need to be made in accordance with the organization's criteria.

d. **Modelling Guidelines**: Defines the basic guidelines (such as: project information, coordinates, definitions, design references, characteristics of properties, types of annotation etc..) that need to be followed using various BIM solutions.

e. **Design & Plan:** Design and Plans developed via BIM must comply with the traditional aspects of the organization, such that their characteristics don't vary from prior designs.

f. **Definitions & Coordination**: Defines where the original BIM project, its revisions and vendor-supplied models will be stored. In addition, the level of detail (LOD) / information (LOI) within the project and IFC interoperability (data standardization policy), among others must be defined.

g. **Strategy & Recommendations:** States the; general structure, the hierarchy of data, building phase, quantity take-off materials, interdisciplinary coordination, project information and system colour-scheme among others.

X. **Implementation Gap Analysis:** Investigates the costs pertaining to the implementation of BIM within the organization. This investigation includes what BIM tools to be used and how the distribution of resource and roles should take place.

XI. **Implementation Planning**: Clarifies and specifies in detail as to what steps need to be taken for the implementation and adoption of BIM within the organization. Hence through this planning, a BIM Execution Plan (BEP) should be delivered. Where the BEP states the guidelines that need to be followed for the successful delivery and optimization of a BIM project.

XII. **Approach & Strategy Rollout**: Defining the objectives the implementation of BIM must accomplish (such as its: mission, vision and motivation) within the organization and the timeline to indicate by when the required objectives are set to meet their goals. Hence a good well-defined implementation plan is crucial for this phase. Within this process, the organization should also research the requirements of BIM and ideal workflows of BIM that they would like to aim towards.

XIII. **Defining a Pilot Project**: During a Pilot Project, the Implementation Process can be checked. Where the goal of a pilot project much analyse if the changes in working methodology from, a traditional work process to a BIM workflow simplifies and improves the overall effect of the team and if goals as set within the BEP plan and project milestone are attainable.

XIV. **Assigning Roles:** Within this process, an overall review of the team members take place where there struggles, achievements, knowledge and skills are analysed from their prior performance within the Pilot Project. Based upon this a selection of

[29] McPartland, Richard. "What Is the PAS 1192 Framework?" *NBS*, 11 Sept. 2017, www.thenbs.com/knowledge/what-is-the-pas-1192-framework.

members who meet the various requirements for the roles of within a BIM workflow will be assigned their appropriate roles within the team.

XV. **Training Strategy**: The training strategy is a mandatory part of the successful implementation and adoption of BIM within a digital work-process. Hence the training should identify address areas of struggle faced by various team members in their appropriate roles and help empower them with theoretical knowledge and practical skills to overcome their struggle. Thus, a group or individual training can be broken down into three-part:

   a. General BIM Training.

   b. BIM work-process Training.

   c. Technological Adaption Training.

XVI. **Defining Data Standardization of Elements**: All data contained within a BIM project must originate from a set of templates, guidelines and information requirements. As indicated within the BIM Protocol the Standardization of Data should take place for all individuals involved with the project including external parties.

XVII. **Compliance & Quality Checks:** Data Compliance and Quality Control of the BIM project and its models supplied from external individuals must be checked against a set guideline. For through the assessment of this process one can evaluate and determine if there are gaps of knowledge or implementation of BIM within the organization or team.

XVIII. **Assessment & Monitoring**: Within the assessment and monitoring aspect the organization must evaluate and analyse if the adoption and implementation of BIM and its digital workflow is a success over that of the traditional methodology. If done correctly then the organization will be able to asses and monitor how beneficial BIM is to the organization. And if there is a continuous assessment and monitoring of the inflow and output of data for the project against project requirements and cooperate guidelines then one can even assess and see an overview of how healthy a BIM project. For one can then assess if the allocation of resources is correctly justified or not.

Hence through the above steps, we can see the steps, policies, protocols, roles and guidelines required for an organization to approach BIM and adopt its methodology and workflow for a project. These steps are also illustrated in the flowchart below.

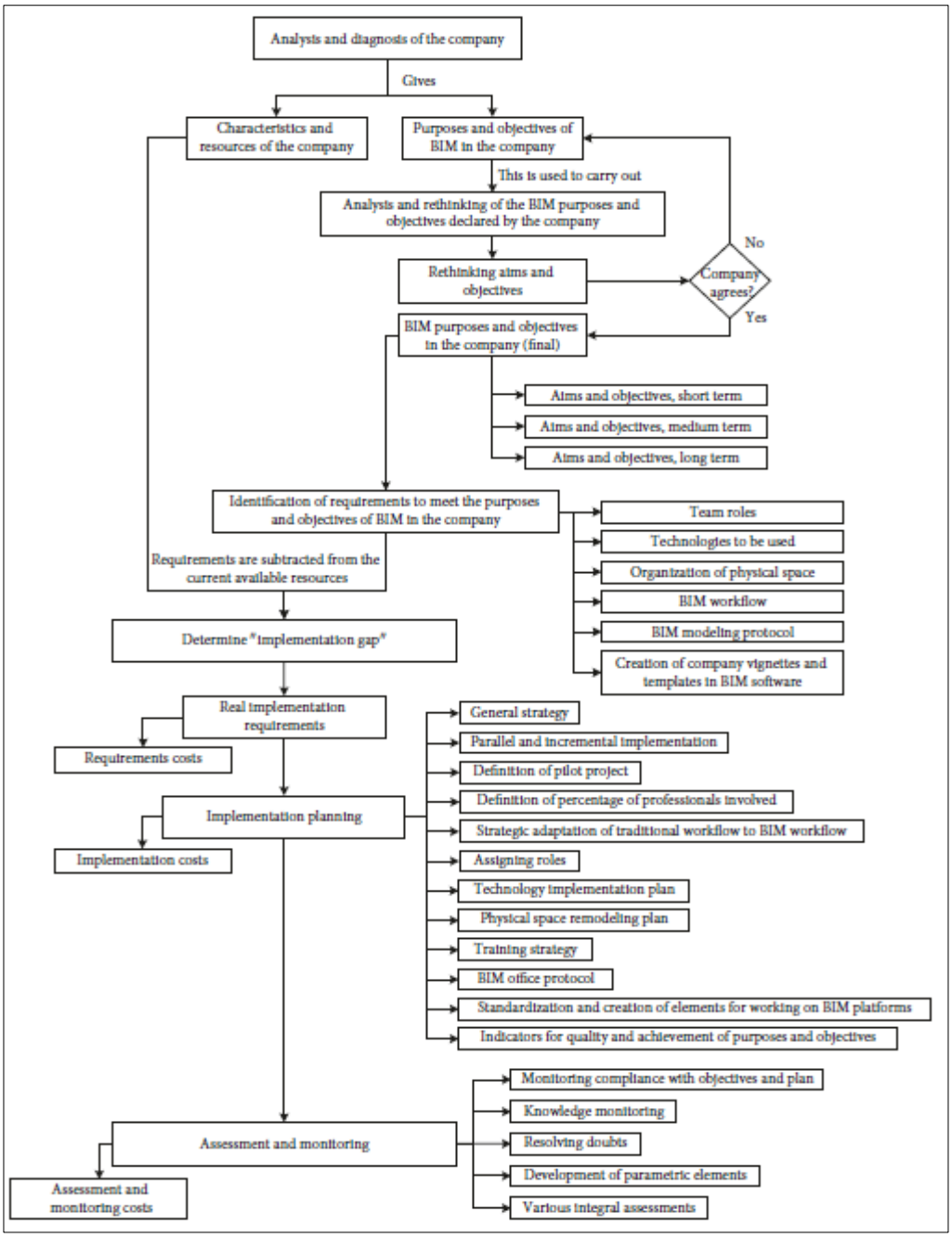


Figure 4: Illustrates the various stages of decisions that need to take place for the successful adoption and implementation of BIM within an organization.[19]

Hence through this section of the paper, we can understand the current internal workflows adopted by some firms within the AEC industry and are also able to understand the process towards BIM adoption and implementation within an organization which wishes to make the transition from a traditional design methodology towards a digital design methodology supported by technological advancements in BIM and its workflows. Where for many the cost factor related towards design modification in the traditional vs digital process is the main factor towards the adoption and implementation of BIM.

C. **How BIM is currently influencing and being used for projects throughout the Building Asset Life Cycle Process?**

As we know by now BIM is complex, its implementation and adoption within the industry requires for either larger organizations (such as: General Contractors) to mandate the use of BIM within their organization and have it as a contractual obligation for third parties (sub-contractors) or via the client through the need from governmental led regulatory policies and mandates. Such adoption of BIM within the industry can be seen within the EU.

Form such standpoint, adoption and implementation of BIM in organizations such as TBI, BuroHappold, Grenzer, Takenaka, KPF, HFB, Skanska, Bond Bryan, ARUP, Arcades, Engie, RoyalHassKoning DHV etc. require the development of a work process methodology, guidelines and policies (such as BEP or BIM protocols) to ensure its success.

Ironically even though the implementation and adoption of BIM aims to help create a digital environment for better communication and data transfer. A common problem within the industry is when an organization implements BIM wrongly within projects due to poor prior planning and understanding of BIM. Hence this may lead to inconsistency in the data structure of BIM projects. This lack of understanding and planning could either be due to the lack of BIM knowledge and execution, thus creating various flaws and gaps in communication between the various involved individuals (such as between the: client, general contractor, sub-contractors and Architect) within the BIM process.

Hence, to ensure that the implementation of BIM within a project and organization is up to the current industrial standard, a set of ISOs (International Organization for Standardization) guidelines was set up through the BSI community. These ISO guidelines ensured that data is standardized and errors in communication or poor modelling can be prevented within the organization and the AEC Industry. A couple of key standards are the ISO 19650[30] (which describes the guidelines for: Organization & Digitalization of Information within the various Phases of the Project such as the Pre-Construction, Construction to Delivery, Operational and Security/Asset Management) & PD 19650[31] (which describes the guidelines for: Organization & Digitalization of Information about Buildings including BIM projects). These ISO standards lay a foundation for data standardization to which organization within the industry must comply.

To help ensure that the ISO guidelines are followed, many organizations develop or make use of a CDE (Common Data Environment) such as Autodesk BIM360,[32] Procore[33] or thinkproject[34] for the storage, coordination and communication of data, issues and tasks between inter-disciplinary or external teams. The role of the CDE is to act as the single true source of information for any project or asset that stores, manages and incorporates this information within a database that can be accessed via the cloud. Hence, stored information in a CDE can be easily coordinated and shared between team members while ensuring that everyone is working on the latest version of the project. Through the implication of a CDE for the internal BIM process, team members can access previous revision of the project and see the chronological history and systematic process followed, while retaining ownership. The Meta-Data fields within the CDE enable members to create tasks for problems with the model (in the form of BCF[35] or RFI's[36]) and help enable them to communicate these tasks/issues/errors to other members by assigning it to them as work that is to be done by them or to their backlog. Hence, the use of CDE is very handy as it enables everyone involved

[30] ISO Group. "ISO 19650-1:2018." *ISO*, 7 Dec. 2018, www.iso.org/standard/68078.html.

[31] BSI Group. "Transition Guidance to BS EN ISO 19650." *BSI PD 19650-0:2019*, 16 Jan. 2019, shop.bsigroup.com/ProductDetail/?pid=000000000030380842.

[32] Autodesk. "Construction Management Software: Autodesk BIM 360." *BIM 360*, www.autodesk.com/bim-360/.

[33] Procore. "Construction Project Management Software." *Procore*, www.procore.com/project-management.

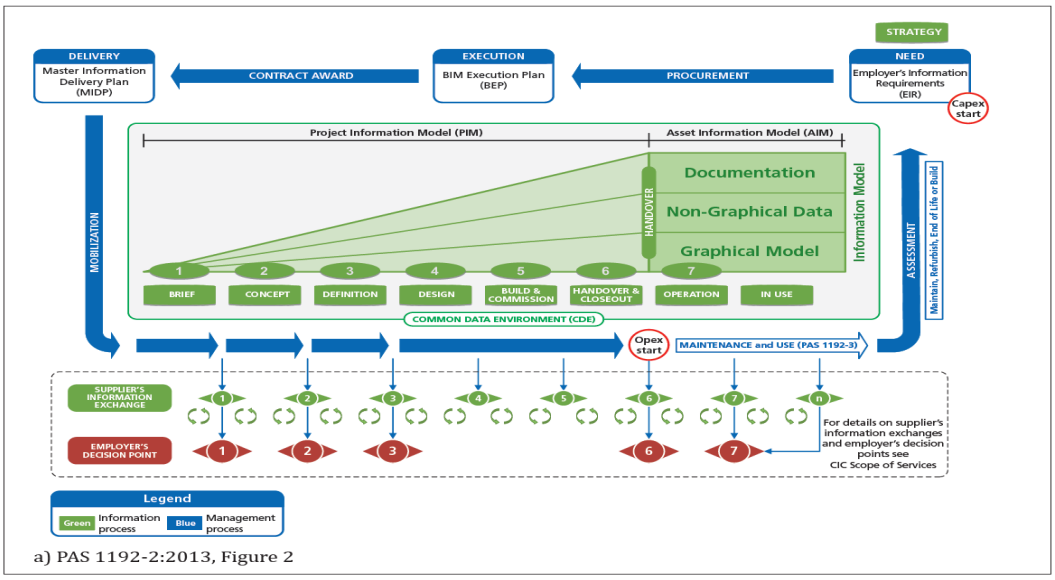
[34] Thinkproject Group. "Common Data Environment." *Thinkproject*, group.thinkproject.com/en/solutions/common-data-environment/.

[35] BuildingSMART International. "BIM Collaboration Format (BCF)." *BuildingSMART Technical*, technical.buildingsmart.org/standards/bcf/.

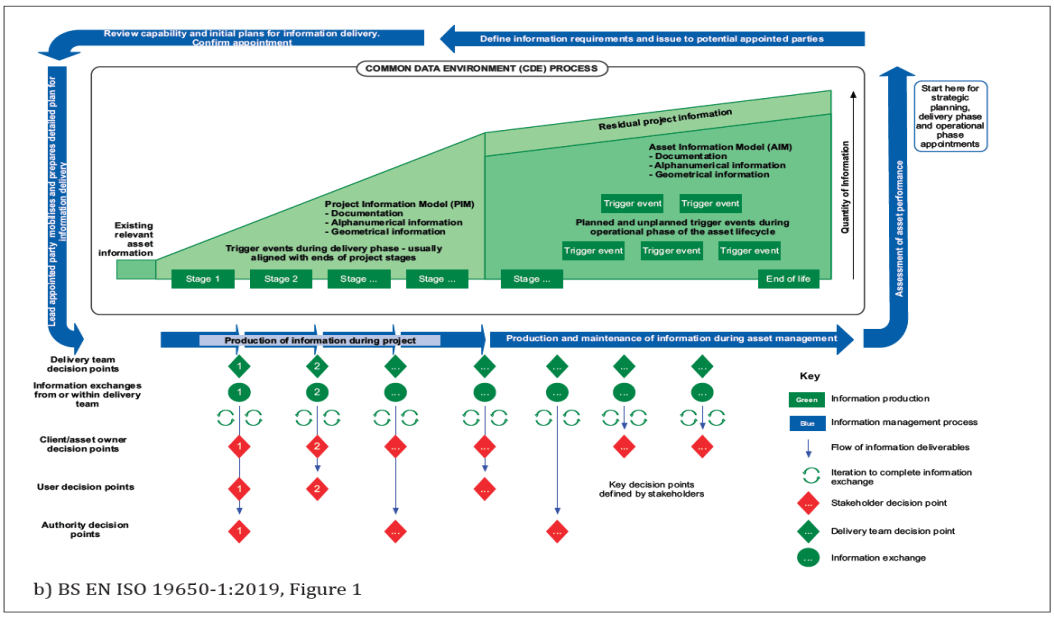
[36] Procore. "Create an RFI." *Procore*, 24 Jan. 2020, support.procore.com/products/online/user-guide/project-level/rfi/tutorials/create-an-rfi.

to get an, easy to access overview of the project and its status while ensuring a that various project milestones are delivered on time.

So, for a BIM Project to start, within the Built Asset Lifecycle we see that an EIR (Exchange Information Requirements) is required. As the EIR would contain documentation on: responsibilities, timelines for phases of the project, acceptance criteria for BIM and accepted documentation formats including the LOD (Level of Detail) & LOI (Level of Information) of the project.[6, 8] The EIR would also contain information on policies and guidelines that need to be adopted during the project lifecycle. After the EIR is agreed upon procurement takes place and a BEP (BIM Execution Plan) is formed. This leads to the formation of the contract based upon the EIR and a MIDP (Master Information Delivery Plan).[6, 8] Where the MIDP is developed from the BEP and is the main plan that contains what all information needs to be prepared. The MIDP thus serves as a tool for defining milestones throughout the project. Once the MIDP is set, a CDE for BIM project is set up and the Information Model is split up into the PIM (Project Information Model) and AIM (Asset Information Model) model.[6, 8] If maintenance or refurbishment is required, then a reassessment of the project within the CDE if required, and the process restarts.



a) PAS 1192-2:2013, Figure 2



b) BS EN ISO 19650-1:2019, Figure 1

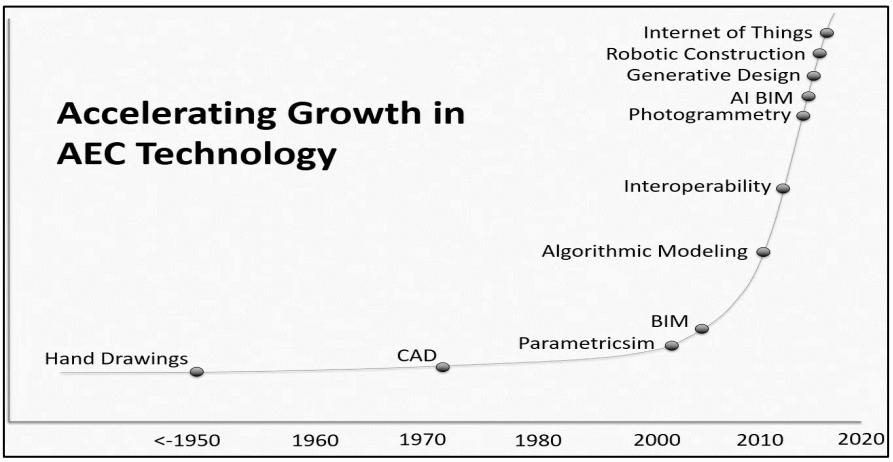
Figure 5: Illustrates the usage of BIM data over the built asset life-cycle process. [8]

Hence to ensure true Data Standardization within the industry many organizations and governments require that along with the native file format of the BIM model an IFC model is also provided; where the IFC[37] (Industry Foundation Class) file format was developed by the buildingSMART community[38] for varying BIM platforms and superimposed models. The use of IFC files were supported by the ISO standard (ISO 16739-1:2018)[39] which enables for one universal data standard in the sharing of information throughout the project lifecycle. It is an open international standard that promotes vendors and organizations with a universal platform that can interact within multiple solutions.[30]

In the case of the Netherlands in addition to the IFC and CDE environment the governmental organization Rijksvastgoedbedrijf (RVB) supports and encourages the use BIM within the country, as BIM provides the organization with focus on improving asset-information in the design, construction, management and operational phase[40]. Where within the Management and Operational Phase the use of BIM, can assist in the monitoring of quality, safety and health of occupants within the building. Hence the RVB developed an ILS[41] (Information Delivery System) system for the Dutch local market which can be used by all involved parties that documents all the required information needed for the management phase. For, the ILS system can be used to validate the data of the BIM model for the Dutch market in the management phase.

D. **<u>What's the future of BIM within the AEC Industry?</u>**

While BIM has been around for a couple of years and is quite well established within the industry, for new building or urban development projects, very limited use of BIM is seen in the maintenance, refurbishment and demolition phase.[42] This is a pity, as BIM promises multiple benefits such as increased efficiency in management of labour and resources for a typical project that adopts BIM along with its processes. Hence, through rapid development in BIM research via multiple private and public-sector companies many involving stakeholders see the benefits in developing new advanced new form of BIM technologies that cater to all phases of a project life cycle.



<u>Figure 6: Illustrates the rapid acceleration in R&D for new digitalization techniques within the AEC Industry.</u> [43]

[37] BuildingSMART International. "Industry Foundation Classes (IFC)." *BuildingSMART Technical*, technical.buildingsmart.org/standards/ifc/.

[38] BuildingSMART International. "What We Do." *BuildingSMART International*, www.buildingsmart.org/about/what-we-do/.

[39] ISO Group. "ISO 16739-1:2018." *Industry Foundation Classes (IFC) for Data Sharing in the Construction and Facility Management Industries — Part 1: Data Schema*, 23 Nov. 2018, www.iso.org/standard/70303.html.

[40] Rijksvastgoedbedrijf. "Rgd BIM Standard v1.0.1 EN v1.0_2." Publication | Central Government Real Estate Agency, Rijksvastgoedbedrijf, 15 Aug. 2018, english.rijksvastgoedbedrijf.nl/documents/publication/2014/07/08/rgd-bim-standard-v1.0.1-en-v1.0_2.

[41] Rijksvastgoedbedrijf. "BIM." *Rijksvastgoedbedrijf*, Rijksvastgoedbedrijf, 18 Apr. 2019, www.rijksvastgoedbedrijf.nl/expertise-en-diensten/building-information-modelling.

[42] Tekla. "Tekla Structures - The Most Advanced Structural BIM Software." *Tekla*, 22 Oct. 2019, www.tekla.com/products/tekla-structures.

[43] Autodesk University. *The Future of BIM*, 23 Nov. 2016, www.youtube.com/watch?v=xq6yKyauu-o.

The increased R&D in BIM has, in turn, lead to many AEC firms following a similar the footsteps of the IT Industry.[43] Where these firms and organizations plan on deepening their commitment to innovation and disruptive technologies and techniques, to enhance and support current digital work process. Hence companies such as Arup, AECOM, Gensler, HOK, TBI, Takenaka, RoyalHassKoning DHV, Skanska, BAM, Bond Bryan and McCarthy among others are trying to embed R&D in BIM, to their organizational DNA. This has led to companies such as TBI and Takenaka to set up a branch of the organization (such as; the TBI SSC-ICT group) to focus solely upon understanding the current and future scope of various digitalization and management technologies and the added-value they bring.

Hence within the R&D, we see the following innovative solutions being developed:

I. **Algorithmic & Parametric Modelling**: The process by which visual programming such as Grasshopper and Dynamo can be used to develop multiple design interactions. Hence the use of Algorithmic and Parametric Modelling enables for more complex designs, patterns and advanced fabrication methodologies to be developed.[44]

II. **Interoperability**: The ability to reuse data and information without the need for remodelling, hence ensuring efficient resource management. Hence the interoperability to manage and change data from differing formats and platforms enables BIM Managers to make use of Analytical Solutions such as Tekla[45] and Solibri[46] for Structural and Code Compliance Checks while ensuring that the modelled data can be brought back to a central platform such as Revit. In most cases to support such interoperability between solutions the IFC file format is used to transfer and translate the information of one platform to another, hence removing barriers to the adoption of various BIM Technologies and Techniques.

III. **Point Cloud for BIM**: Point Cloud is an advanced Image Analysis solution for BIM within the AEC industry that is mainly used in renovation, maintenance, surveying or facility management of projects. Point Cloud captures a virtual 3D representation of an area within a model, thus enabling the BIM Modular to create accurate BIM projects of buildings that previously didn't contain any digital plan. The use of Point Cloud technology also helps municipalities to create virtual representations of streets and urban areas to help understand what impact urban development can have upon the location.[47]

IV. **AI BIM:** Machine Learning (AI) and BIM are two very exciting forefronts of current R&D within the industry. Platforms such as Microsoft Azure, Google Cloud, and Amazon AWS among others give companies the chance to develop their solutions to tackle varying issue within the industry where AI can be the solution to these problems.[48,49] From data analysis to statistics and building-environmental simulations, high-end computation is required. Currently, the use of AI can be seen in BIM where menial and repetitive tasks are assigned for completion by smart algorithms. Hence the companies within the industry are trying to win the race to see who is faster in developing a solution where AI can be applied to every aspect of operations, documentation and management.[50] For the use of AI and BIM can enable

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[44] Caetano, Inês, and António Leitão. "Integration of an Algorithmic BIM Approach in a Traditional Architecture Studio." *Journal of Computational Design and Engineering*, 29 Nov. 2018, www.sciencedirect.com/science/article/pii/S2288430018300617.

[45] Tekla. "Tekla Structures - The Most Advanced Structural BIM Software." *Tekla*, 22 Oct. 2019, www.tekla.com/products/tekla-structures.

[46] Solibri. "About BIM and IFC." *Solibri*, www.solibri.com/bim-ifc.

[47] Corke, Greg. "From Point Cloud to BIM." *AECMAGAZINE* , 12 Mar. 2015, aecmag.com/59-features/829-from-point-cloud-to-bim.

[48] Chuang, Tien-Hsiang & Lee, Bo-Cing & Wu, I-Chen. (2011). Applying Cloud Computing Technology to BIM Visualization and Manipulation. 10.22260/ISARC2011/0023.

[49] Ford, Martin, et al. *The New Era of Computational Productivity*. h20195.www2.hp.com/v2/getpdf.aspx/4AA7-4082ENW.pdf.

[50] Briq, Inc. "THE RACE IS ON Using Analytics and Machine Learning in Construction." *Briq White Paper*, 2019, static1.squarespace.com/static/5c36f5a7e17ba3903fa09a5d/t/5d8d7bd9f8f69c052418b25c/1569553371324/The Race is On, Analytics and Machine Learning in Construction.pdf.

Automated Generative Design, Task Automation and Efficient Data Optimization / Management within the organizations where design choices can be backed by the use of Data-Informed Design Decision to predict and guarantee the success of the project.[51]

V. **Generative & Augmented Design**: Virtual (VR) and Artificial (AR) Reality have become quite popular today where the applications of such technology are quite at large within the industry.[52] Using AR & VR Technology in products such as Microsoft HoloLens or Oculus Rift, Architects and General Contractors can visualize spaces and rooms through the Digital Twin of the BIM Project. This enables General Contractors to identify issues prior to the construction process, such as detecting clashes and accessible spaces between elements. Thus, preventing costly mistakes and delays within the construction phase. In addition to the use of AR & VR, AI and Point Cloud can be used to simulate changes or modification made to an existing construction, thus enabling the General Contractor to walk through the virtual model and identifies issues. Using generative design algorithms multiple design variants can be produced and visualized in an AR or VR environment, hence enabling the BIM Coordinators to perform an interactive code compliance check of the project.[53]

VI. **Robotic & Digital Fabrication**: Computer Assisted Fabrication enables for complex shapes to be constructed via 3D printing (on differing material), Laser Cutting and CNC Milling. For Computer Assisted Fabrication via the help of AI can lead to a fully automated manufacturing and assembly plant.[54,52] Trough the help of BIM models, element data and geometries can be used to produce digital prefabricate of modular building elements that can be sent to the construction site for on-site prefabrication and assembly. Through digital fabrication and automated manufacturing, Architectural Beurres can hence experiment with various designs and materials to help understand the boundaries between form and material composition of elements.[55]

VII. **IoT & Cloud**: The key focus of IoT (Internet of Things) is connectivity and sharing of information between digital and physical devices.[51] Where within the construction industry sensors are used to communicate data over key aspects of the progress of the project. Through the help of open data formats, and the ability to work in harsh environments, these sensors can track events on the construction site[56] (such as; finding the rate at which building material are being brought to the site and for how long do they stay on the site prior to assembly) and share this knowledge to big data mining cloud computation devises to help analyse and suggest areas within the current construction process that can be improved hence allowing for better management of time and resources.[57] Hence IoT's data can be mined under any context, on any network, anywhere and on any device. With the internet becoming more freely accessible throughout the world through mobile carriers and with

[51] Galay, Marie. "How AI Is Improving BIM and Helping the Construction Industry." *Kreo*, 28 Oct. 2019, www.kreo.net/blog/how-ai-is-improving-bim-and-helping-the-construction-industry.

[52] Sampaio, Alcínia Zita. "Enhancing BIM Methodology with VR Technology." *State of the Art Virtual Reality and Augmented Reality Knowhow*, IntechOpen, 12 Apr. 2018, www.intechopen.com/books/state-of-the-art-virtual-reality-and-augmented-reality-knowhow/enhancing-bim-methodology-with-vr-technology.

[53] Vicario, Pedro & Ródenas López, Manuel & Martínez, Marta & Córdoba, Miguel & Martí, María & Ros-McDonnell, Diego. (2016). AUGMENTED REALITY AND GENERATIVE DESIGN. A TOUR THROUGH PRINT MEDIA FOR DESIGNING AND REPRESENTING ARCHITECTURE. 4769-4777. 10.21125/edulearn.2016.2143.

[54] Day, Martyn. "The Rise of the Robots." *AECMAGAZINE*, 8 Dec. 2015, aecmag.com/component/content/article/59-features/1036-the-rise-of-the-robots.

[55] Day, Martyn. "Embracing Digital Fabrication." *AECMAGAZINE*, 20 May 2019, www.aecmag.com/technology-mainmenu-35/1806-embracing-digital-fabrication.

[56] Dave, Bhargav, et al. "A Framework for Integrating BIM and IoT through Open Standards." *Automation in Construction*, Elsevier, 14 Aug. 2018, www.sciencedirect.com/science/article/pii/S0926580517305964.

[57] Teizer, Jochen, and Markus König. "Internet of Things (IoT) for Integrating Environmental and Localization Data in Building Information Modeling (BIM)." *34 Th International Symposium on Automation and Robotics in Construction (ISARC 2017)*, 2017, pdfs.semanticscholar.org/15f6/d89d1fb9d9b198cab1720d7723550d7a5624.pdf.

upcoming technologies such as 5G the use of IoT's for information gathering and communication will be widely seen throughout the industry.[51,58]

So, what does the above-mentioned disruptive technology mean for the industry? Well for organizations such as Takenaka, Skanska, TBI and BAM among others see the future of BIM is in IoT's and Cloud ventures where they can move all their data management of BIM projects and documents to a digital cloud infrastructure for ease of accessibility and management. An example of this is Skanska (a major construction organization) that's in the transition period of fully moving their data to a cloud environment where BIM projects can be analysed, managed and modified remotely. While using Cloud Computation they plan on using AI for automation of repetitive tasks. [59]

Within the industry we also see differing levels of BIM maturity[60] with the following dimensions:

I. **3D BIM**: Information Management, Data Coordination and Graphical Analysis.

II. **4D BIM**: Time Management.

III. **5D BIM**: Cost and Material Analysis.

IV. **6D BIM**: Sustainability Assessment.

V. **7D BIM**: Project Management.

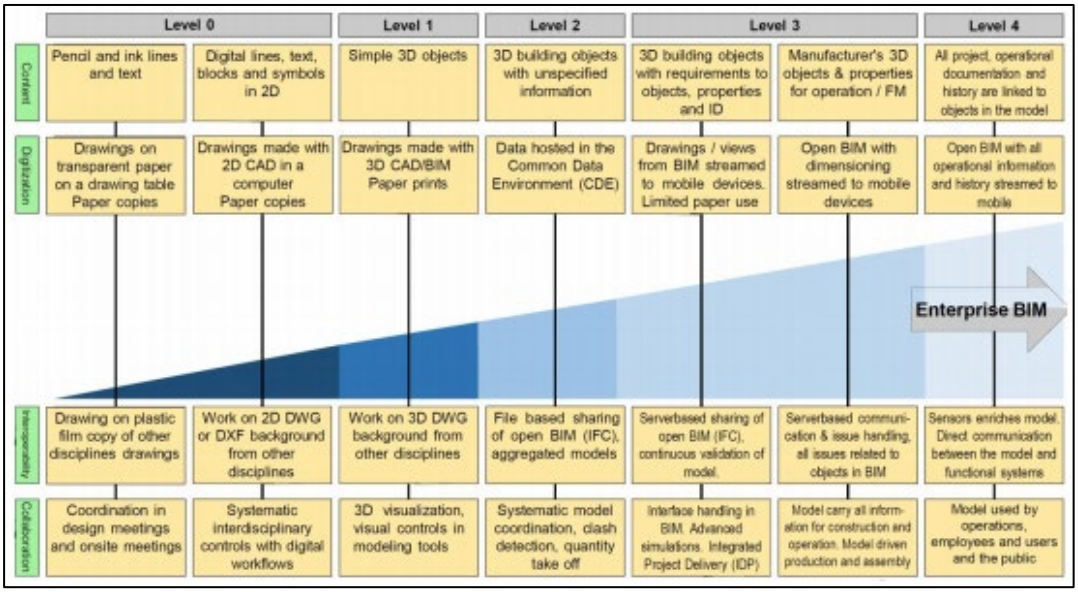

Figure 7: Illustrates the varying levels of BIM within the industry.[15]

Hence through the various levels of BIM realistic and innovative solutions are being developed for the industry to make it more efficient where this possibility exists due to the constant R&D in the BIM industry.[61]

[58] Group, IBM. "What to Expect from 5G and IoT for Smart Spaces." *Internet of Things Blog*, 23 May 2019, www.ibm.com/blogs/internet-of-things/iot-what-to-expect-from-5g-network/.

[59] Hickins, Michael. "Construction Giant Skanska Using Cloud As Foundation For Growth." *Forbes*, Forbes Magazine, 9 June 2017, www.forbes.com/sites/oracle/2015/10/31/construction-giant-skanska-using-cloud-as-foundation-for-growth/#5744e3c06ccb.

[60] United-BIM. "BIM Maturity Levels Explained- Level 0: 1 : 2 : 3 :" *United*, 10 July 2019, www.united-bim.com/bim-maturity-levels-explained-level-0-1-2-3/.

[61] Kensek, Karen M., et al. *Building Information Modeling: BIM in Current and Future Practice*. Wiley, 2015.

E. **Will BIM and its technological advancements change how AEC professionals will work in the future and will it intern change how we perceive and define an Architect to be?**

By 2050, 70% of the world's population will live in Urban Cities and 46% of the global population is bound to increase from 2000 to 2050.[62] This indicates that a large demand for infrastructural and construction projects will exist; where it's expected that 55% of global construction projects will take place in emerging markets VS. 45% in developed markets.[62]

As currently seen within the AEC industry BIM technology and its R&D form's an integral part of the project lifecycle for many firms, organizations, governments and regulatory bodies. Although just like any other technological innovations and adoption BIM requires firms to stay up to date with latest techniques and tools. Hence many within the AEC industry recruit a young workforce that's more tech-savvy to stay intune with the latest and greatest innovative developments within their industry.[63] This shift in recruitment and technological advancements has led many experts and senior figures within the industry, to describe the loss of a generation of traditional architects as a threat to the roots and roles that define an Architect.[61] In a 2008 study it was reported that a 40% decrease in demand is seen for Traditional Architects within the UK.[62]

Hence the effect of BIM and its process intern have a knock-on effect upon the industry where a growing number of projects will be taken by large organizations as most clients and organizations are driven by simplicity, practicality and price.[62] For large organizations can offer more cost-effective and bundled business discounted packages than Small Medium Enterprise's (SME's).[62] Thus, being more attractive for international clients and governmental offices as through a larger organization project risks can be managed and migrated through various divisions of the organization hence mitigating the typical risk involved when commencing and executing a project.[62,63] This, in turn, has prompted the industry to procure multi-skilled young talented individuals that can fit within a Large Organization which caters towards the whole built asset lifecycle (such as: do-it-all general contractors).[63]

Although there will always be clients that want award-winning buildings, they will always look for well-renowned Architects and firms that have a strong foundation within the industry. Similarly, replete clients will always continue their partnership with their supplier and hence commission key firms or Architects. For this will not only increase the brand recognition of the firm but will also lead to a level of exposure and recognition within the industry for the project.[62,63]

Currently, an Architect is seen as a draftsman who designs (a part of) a building within a project while coordinating with other team-members. Where the roles of a contemporary Architect were broken down and a majority of which are currently taken over by the Engineer and Project Manager.[62] This has led Architecture to be an essential aspect of today society, as it contributes towards societal and environmental needs while ensuring a better lifestyle.[62] As Architects work in a multi-disciplinary team to fulfil their role. Their spatial awareness and contextual thinking allow for an Architect to solve complex planning and design problems, while keeping the requirements of the client key to the success of the project.[62]

Today's Architects are under a lot of pressure form rapid change within the industry. This has led to the distribution of tasks and responsibilities between team members and project partners.[62] Hence a new form of co-operation within the workforce is created, that diversifies roles and responsibilities among team members. Hence Architects must constantly fight for their position and responsibilities within the project.[62] Consequently, new opportunities are opening for Architects to take on, whereby gaining new skills they can extend their boundary, of roles and responsibility.[62,63]

[62] Jamieson, Claire. *THE FUTURE FOR ARCHITECTS?* RIBA, www.researchgate.net/publication/240916942_The_future_for_Architects.

[63] Vos, Marina Bos-de, and Bente Lieftink. "Future Roles for Architects: an Academic Design Guide." *BK BOOKS*, TU Delft, 1 May 2018, books.bk.tudelft.nl/index.php/press/catalog/book/isbn.9789463660242.

This new form of opportunities is due to integrated contracts[62] being awarded by clients to do-it-all corporations within the industry.[62,63] Where these organizations take the sole responsibility of completing the project throughout the built asset lifecycle process (so from design to construction and delivery to sometimes even the maintenance phase).[62] As integrated contracts simplify the process of procurement for clients and help reduce the risks involved when commissioning a project, as the sole prime responsibility of the project falls upon one organization and its multi-inter disciplinary teams.

An added benefit to a multi-disciplinary work-methodology is where, it gives an Architect of the future the ability to extend their portfolio of skills. As it gives them an opportunity to become a vital member within the organization through learning new skills and gaining knowledge in multiple disciplines within the organization. Hence the role of the future architect will become more diverse and inter-disciplinary whereby enabling them to develop their skills as an initiator, specialist, product developer, integrator and analyst.[63] In many cases, the younger generation of Architects have this possibility to design their own future role as an Architect as organizations start to diversify tasks and roles.[63] In response to what we consider and value and Architect to be, it's also seen that younger professionals have a strong desire to be part of a broader multi-interdisciplinary organization.[63] For this enables the younger professional to seek multiple carries paths leading to a wider range of roles and responsibilities within the AEC Industry.

Hence in order to survive in such a technical and rapidly developing industry, the Architect of the future must develop new multi-disciplinary technical skills that that can develop their role within the industry to the changing of times. For, topics such as sustainability, disruptive technology, new construction materials, big data simulation and changes in the urban landscape will result in changes within the industry for procuring requirement of an Architect of the future.[62,63]

F. How can BIM help in the process of validating building projects for governmental regulatory bodies?

BIM is a very flexible and advanced data collaboration and management system. Through the help of CDE's, EIR's, BEP's, BIM protocols and Open Data Formats such as IFC and BCF the standardization of data within the AEC Industry can take place. To support this international regulatory standards such as the ISO 19650 (Organization and digitization of information in BIM throughout the built asset life-cycle)[64] along with the ISO 23387 (Data templates for objects used in the built asset life-cycle)[65] were developed to help set a guidelines to which firms must adhere to when standardizing the data structure of objects and elements within BIM.

In a standard Design-Build (DB) process only 5% - 10% of the information is check.[65] Whereas Automated Code Compliance Checking Tools have led to 40% to 60% of design validation.[66]

This has led to many governments (such as the: UK, UAE and Singapore) around the world required governmental departments to electronically validate BIM projects and superimposed models and objects from vendors before approval.[67] The Singapore government does so by using data validation tools (such as Solibri, Navisworks, Verifi3D among others) to check for data consistency as per local and international guidelines. Though the use of such BIM validation software the Government along with BIM Coordinators & Managers can check the quality of the model to ensure its accuracy while running appropriate data validation check on

[64] ISO Group. "ISO 19650-1:2018." *ISO*, 7 Dec. 2018, www.iso.org/standard/68078.html.

[65] ISO Group. "ISO/DIS 23387." *ISO*, 30 Jan. 2020, www.iso.org/standard/75403.html.

[66] Ciribini, Angelo, et al. *Informative Content Validation Is the Key to Success in a BIM-Based Project*. Jan. 2016, www.researchgate.net/publication/292150721_Informative_content_validation_is_the_key_to_success_in_a_BIM-based_project.

[67] Ravenscroft, Tom. "Government BIM Mandate to Include Data Validation by October 2016." *BIM* , 22 Oct. 2015, www.bimplus.co.uk/news/new-bim-ma1ndate-deta2ils-include-da2ta-validation/.

its data structure and information.[68] This data validation is done through the help of rules-sets and rules, that can check the data property of each element/object to ensure its structure, accuracy and code compliance.[68]

In the case of the Singapore Government, they have issued an innovative grant that's funded by the Ministry of National Development Launches which calls for an Automated Code Compliance Checking Tool for BIM Models.[68] Through such a tool they wish to assist the AEC industry in self-checking their planes and BIM models, before submission for governmental approval.[68] Where the tool can help detect issues in the early design and pre-construction stage to ensure unforeseen issues don't lead to costly delays or safety concerns. Hence through an Automated Code Compliance Checking Tool, they wish to overcome costly and unnecessary rework before the building may be commissioned.[69]

Via the grant they wish to:

I. Assess and Develop current technologies to create a BIM Model Checks that validates models based upon rules and rulesets per AEC discipline.[68]

II. Improve the overall productivity and simplify the process within the industry for all involved parties including governmental regulatory bodies. By being able to identify and resolve non-compliance issues prior to regulatory submission and construction.[68]

Hence, through governmental led initiatives, innovation takes place and many solutions are developed. These solutions are then assessed against their value-added generative for the organization or industry.[65] One such solution that meets the requirements of many is Solibri, for within the solution BIM Coordinators can set their own rulesets that need to comply towards governmental regulations and project guidelines. Hence through the solution, errors and issues in non-compliance can be detected early on within the project life cycle and reported back to the BIM Modeler in the format of BCF or RFI files.

For within the process the BIM Coordinator runs checks upon the BIM Project to ensure that it meets the necessary requirements. Intern any errors found by the BIM Coordinator are reported back to the BIM Modular who corrects the issues within the project. Subsequently, the BIM Review board consisting of BIM Engineers review the project as a whole and ensure that all guidelines and cross-disciplinary validation check are met. Based upon the results of the review board the BIM Leader seals his approval or disapproval for any aspect of the model. Throughout this process, the progress of the project is constantly electronically monitored and Information Takeoffs (ITO's) of the Data Validation results can be generated for regulatory bodies to approve upon. [70]

Hence with the future of Architecture changing its believed that, through disruptive technology such as Automated Code Compliance Tools for BIM, many Architects will develop new skills in the Data Quality Assurance (QA), Data Quality Control (QC) and Regulatory aspect of data validation of BIM models.[63] This shift in skills will be seen through a do-it-all large multi-disciplinary organization (general contractor) or for governmental and regulatory organizations such as the Building and Construction Authority, (BCA)[67] body of Singapore.

Thus, Data Validation in BIM is Code Compliance and checking the Quality of Data within the model. For the code compliance aspect must analyze the model (through the various other disciplines) to ensure that it meets project or local guidelines (i.e. check dimensions to verify design compliance to regulation on aspects such as accessibility and minimum special

[68] BCA. "Singapore BIM Guide." *Building and Construction Authority*, May 2012, www.corenet.gov.sg/media/586135/Singapore_BIM_Guide_Version_1.pdf.

[69] BCA. "2-STAGE INNOVATION GRANT (IGRANT) ." *Building and Construction Authority* , 1 Sept. 2016, www.bca.gov.sg/ResearchInnovation/others/Automated_Code_Compliance_Check_in_BIM.pdf.

[70] Biblus. "BIM and Model Checking: What It Is and Why Validation Data Processes Are Needed." *BIM and Model Checking Applied to the Single Disciplinary Model and to the Integrated Model (Merged Model)*, 18 Oct. 2017, biblus.accasoftware.com/en/bim-model-checking-validation-data-processes-needed/.

requirements for differing functional areas). While Data Quality investigates if all the mandatory information related to a building object within the BIM file has been specified. Hence the Data Quality aspect of the Data Validation process would check the name, object type, location, relation to other objects and parameters of the object. While Code Compliance must take into consideration the geometry and data properties of objects. As the end goal of Data Validation should ensure that the model is Code Compliant, and QA/QC approved, thus overcome costly and unnecessary rework before the building may be commissioned.[67]

3. Discussion:

It has only been 20 years since BIM was first introduced in a whitepaper from Autodesk.[6] Since then through the help of new technical advancements such as AI, AR and Cloud Computation, the future of an Architect and those within the AEC industry is bound to change. This change within the work process, and a shift in organizations and policies towards the adoption of BIM over the traditional design process indicates that the industry is ready to adapt to the new age of digitalization.

This change is seen when one visits events such as: Autodesk University, Digital Construction Week and NXTBLD, where there is a growing consensus among the AEC community for embracing change and embedding new advancements in BIM, hence ensuring a more efficient and sustainable future for everyone within the industry.

Technology can become a positive force as the global population continues to increase, and automation takes over repetitive tasks through AI and predictive simulation. As half the growing global population are middle-income individuals, this will result in more demands for housing. Hence the construction sector is bound to boom over the upcoming years in emerging markets. Although this boom in construction also has a negative impact on the environment where resource-scarcity due to ever-growing consumer demands will be a problem. Hence, the use of technology for sustainable, green, innovative and efficient ways of design and construction will be a key positive force in the future. This paves the way for a Circular Economy by reducing, reusing and recycle materials and knowledge. For, currently the construction and demolition accounts for approximately 25% - 30% of all waste generated within the EU.[71]

Why knowledge? Well currently with an ageing generation of traditional AEC professionals specialized in their own field of expertise many organizations such as TBI are facing a problem where they wish to transfer the knowledge of skilled professionals to the younger generation, Though this may sound easy to do, it's quite difficult and time-consuming. Hence, to simplify the process and bridge the gap between the older and younger generation, TBI makes use of technological advancements in BIM, to automate and digitalize some of these specialized tasks in the format of data validation scripts and algorithms. Rule-based data validation algorithms enable Automated Code Compliance Tools to check and validate BIM models against specific specialized requirements. Automation within the AEC Industry will hence lead to new roles being defined for more meaning full work.

Data Interoperability and Validation also helps in reduction of rework. For around 30% of the work currently performed by general contractors is project rework.[72] Due to lack of trust between project deliverables from external parties, this is a major problem within the industry. In the US market project rework results in a loss of $31.4 Billion[72] due to incorrect, poor project deliverables or due to miscommunication errors. From which $4.2 Billion[72] is due to poor and incorrect document control. This accounts for an average total loss per project of 9%.[72] Hence many organizations have started to implement Code Compliance (CC), Data Quality Assurance (QA), Data Quality Control (QC) and BIM Protocols. Through such innovative implementations, they wish to detect issues and reduce risks early on within the built asset life cycle process via interoperable open-standard file formats such as IFC, BCF and RFI's. 78% of Engineering and Construction firms

[71] European Commission. "Construction and Demolition Waste ." *European Commission*, 7 Aug. 2019, ec.europa.eu/environment/waste/construction_demolition.htm.

[72] Ellis, Grace. "100 Construction Industry Statistics To Improve Productivity." *PlanGrid Construction Productivity Blog*, 3 May 2019, blog.plangrid.com/2018/08/construction-industry-statistics-to-improve-productivity/.

believe that the overall project risk is increasing.[72] Hence, data validation, quality and code compliance will become more centric to the BIM Process, as regulatory bodies (such as the BCA) require projects to be checked before the project receives governmental approval. Thus, reducing risk and errors.[68]

The use of technological advancements in the construction sector is also bound to increase productivity. For over the last two decades, the sector has seen an increase from 1% to 3.6%.[5] This lack of productivity is mainly due to the lack of adoption within the sector for digitalization and standardization of data. Currently, 40% of construction firms sill make use of traditional methodologies.[72] This % of adoption for digitalization is bound to increase but will face its challenges due to legacy systems and work methodologies. Hence, via digitalization it's seen that 32% of construction firms see an average saving of 5 hours per week[72] over that of traditional work methodologies. Thus, saving $1.63 trillion annually within the construction sector if productivity changes.[72] In this quest to increase productivity and reduce project risk, 62% of AEC firms experiment with new technological solutions.

Firms in the AEC industry spend 5x less on IT than in other industries, only 1% of their overall profits.[72] Although, technological advancements in theory can increase overall productivity of an organization within the construction sector, in practice its quite different. Current statistics[72] show that only 40% of firms within the industry invest in R&D for new technological advancements.[72] Why is this % so low? Well, it mainly has to do with firms unable to break their current working methodologies and policies to discover new technical opportunities and advancements for a more efficient future. For even though a new innovative solution might exist within the industry that help benefit the firm, 59% of construction firms don't have the required expertise (support, training, workers, time) to develop a new process to replace those of legacy systems.

Despite this, many firms still push on with their quest to achieve full digitalization. Similar statistics[72] show that a full-scale industrial adoption of digitalization within the next 10 years will result in $0.7-1.2 Trillion or 13–21% in the Design and Construction phase and $0.3-0.5 Trillion or 10-17% in the Management and Operational phase. For, the use of AI is bound to increase cooperate profits by 71% from 2019-2035.[72] Hence, as businesses are always driven by simplicity and efficiency, it will only be a matter of time for current legacy systems to be replaced by innovative technological solutions and design process.

This change will re-define the way organizations within the industry will allocate roles and procure professional workers. For, the future role of many AEC professionals will become more diverse and inter-disciplinary whereby enabling them to develop multiple skills as an initiator, specialist, product developer, integrator and analyst.[63] Through the use of disruptive technologies such as Automated Code Compliance Tools for BIM, many Architects will develop new skills in the Data Quality Assurance (QA), Data Quality Control (QC) and Regulatory aspect of data validation of BIM models.[63] This shift in skills will be seen through a do-it-all large multi-disciplinary organization (general contractor) or for governmental and regulatory organizations. This will lead to many organizations within the AEC industry starting the process of procuring workers that meet the future demands of the industry.

Due to disruptive technologies and changes in procurement requirements, it's expected that a restructure of the labour workforce within the industry will create labour shortages. Currently, less than 80% of firms in the construction sector can't procure the required skilled future-proof workers they require.[72] Fortunately, due to the ever-growing demand for smart-homes and cities along with innovation in BIM (such as: Digital Twin) it's expected that current skilled jobs will morph into new roles, as professional will gain multiple carries paths leading to a wider range of roles and responsibilities within the AEC Industry. For, within the US from 2018 to 2028 the number of jobs in the construction sector (with an average wage of $46,010 in 2018) is expected to increase by 9.8% and in the Architectural Engineering sector (with an average wage of $80,170 in 2018) by 4.2%.[73] This projected increase of jobs is seen globally and more so in emerging markets, where 55% of global construction projects will take place.[62]

[73] U.S. BUREAU OF LABOR STATISTICS. "Employment by Major Occupational Group." *U.S. Bureau of Labor Statistics*, 4 Sept. 2019, www.bls.gov/emp/tables/emp-by-major-occupational-group.htm.

4. Conclusion

In answer to the main research question of this paper as to how policies, workflows and process can set the tone towards adoption and implementation of BIM within the AEC industry, and how the future of BIM and Data Validation can influence the future of Architects, the following can be concluded.

The adoption and implementation of BIM is mandatory for increased productivity and efficiency through the digitalization of work processes. This is only possible via governmental policies and mandates that require the use of BIM via large-organizations and clients during the procurement process. For an organization to shift from a traditional design work methodology to that of a digital design methodology, the implementation of a BEP (BIM Execution Plan) along with the framework of a BIM workflow and a BIM Protocol is required. Through such policies the roles and responsibilities for project deliverables can be defined in a digital design methodology aided using BIM.

As the future of BIM and R&D in the AEC Industry continues to develop, new advancements in disruptive technologies are bound to change the way we work. Hence its seen that architects of the future will need to develop new multi-disciplinary skills, whereby enabling them to seek multiple carrier paths with a wider range of roles and responsibilities. Such a role and responsibility for future Architects will be to develop new skills in the Data Quality Assurance (QA), Data Quality Control (QC) and Regulatory aspect of data validation of BIM models. They will be able to do so via data standardization and interoperability between organizations and regulatory bodies.

Hence, policies and process will set a positive tone towards the adoption and implementation of BIM. Data validation, standardization, quality and compliance will be a key focus of future AEC professionals. Hence, advancements in this new technologically innovative solution of BIM for the industry will refine the “who an Architect is”.

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6. Appendix:

Figure 1: Illustrates the usage of BIM during the Built Asset Life-Cycle Process for thr various sectors of Design and Engineering, Construction and Operation. [15]

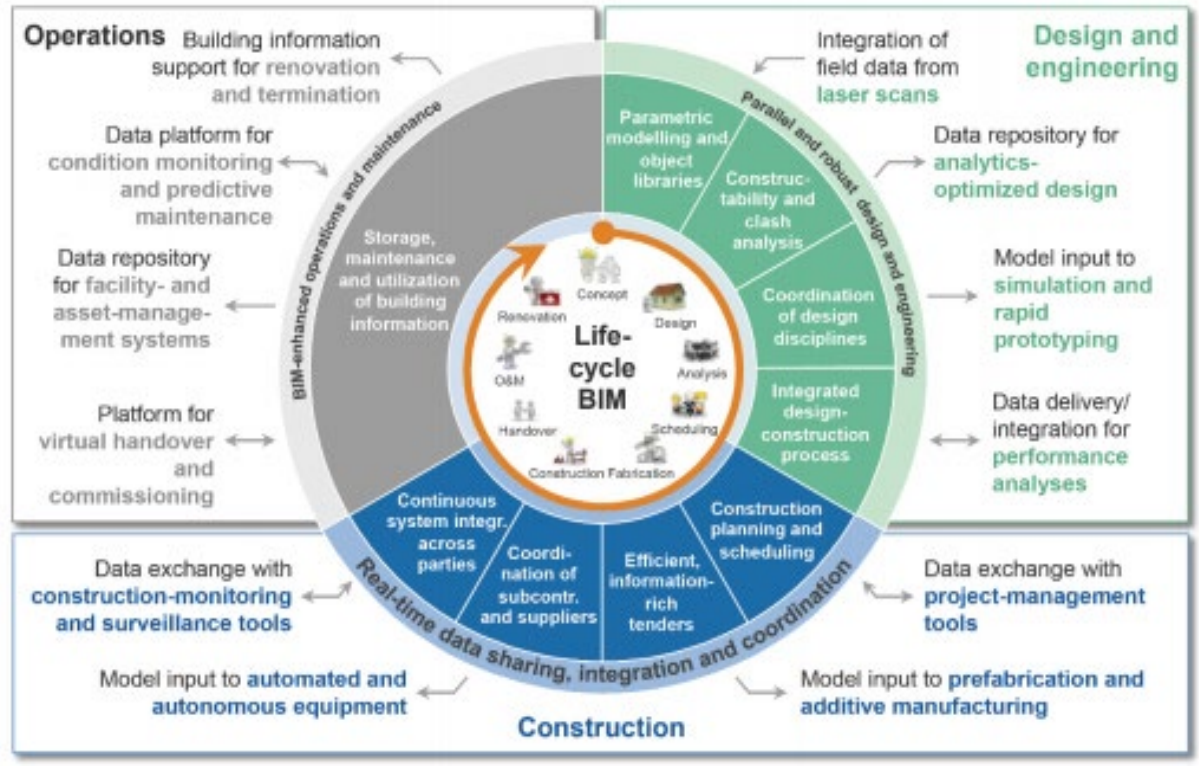


Figure 2: Illustrates the cost of implementing changes over various phases of the built asset life cycle, when comparing traditional over BIM design methodologies. [26]

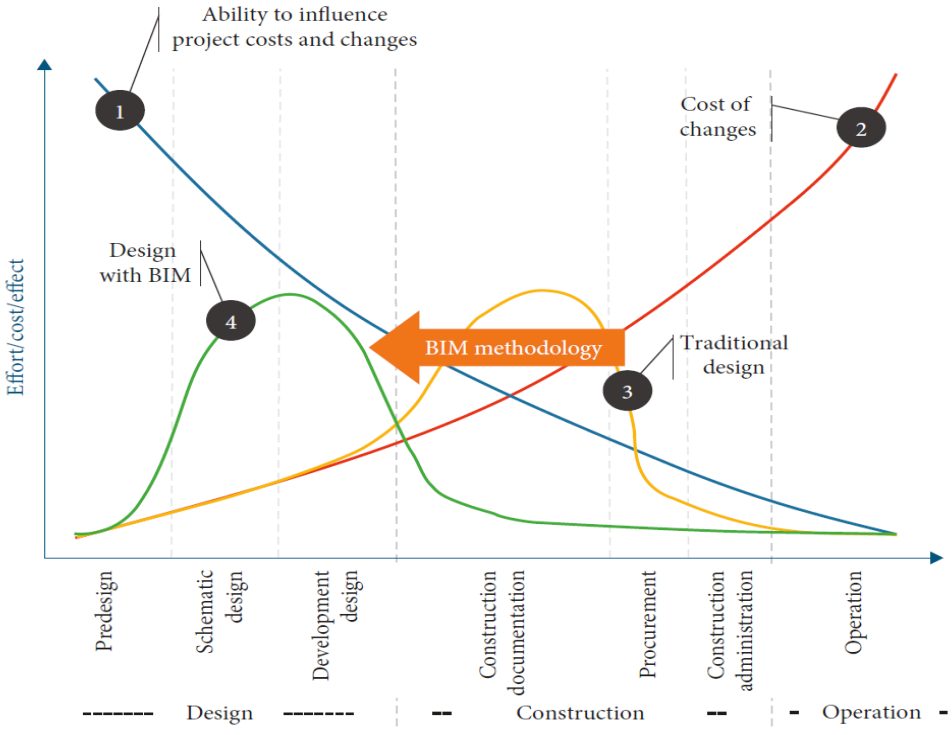


Figure 3: Illustrates an example of an ideal BIM workflow for a project within an organization.[19]

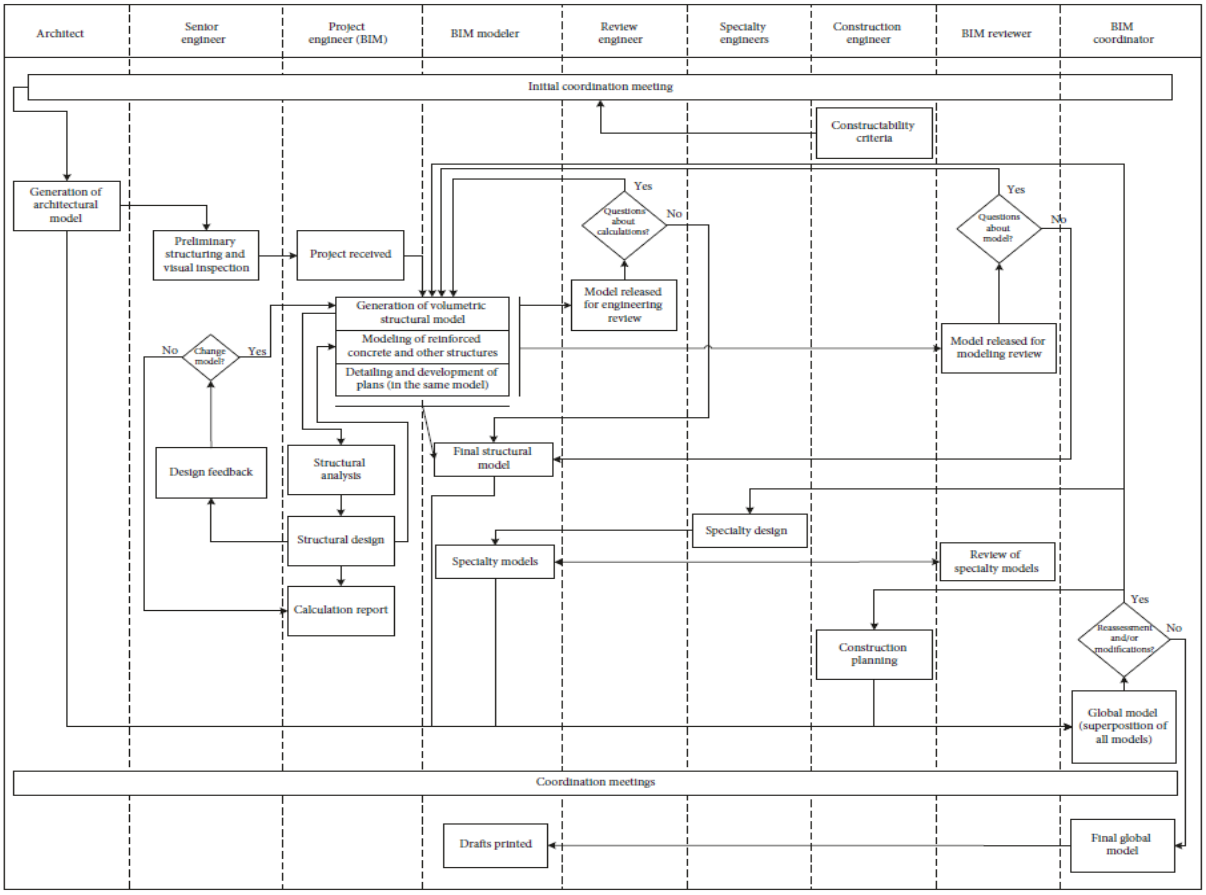


Figure 4: Illustrates the various stages of decisions that need to take place for the successful adoption and implementation of BIM within an organization.[19]

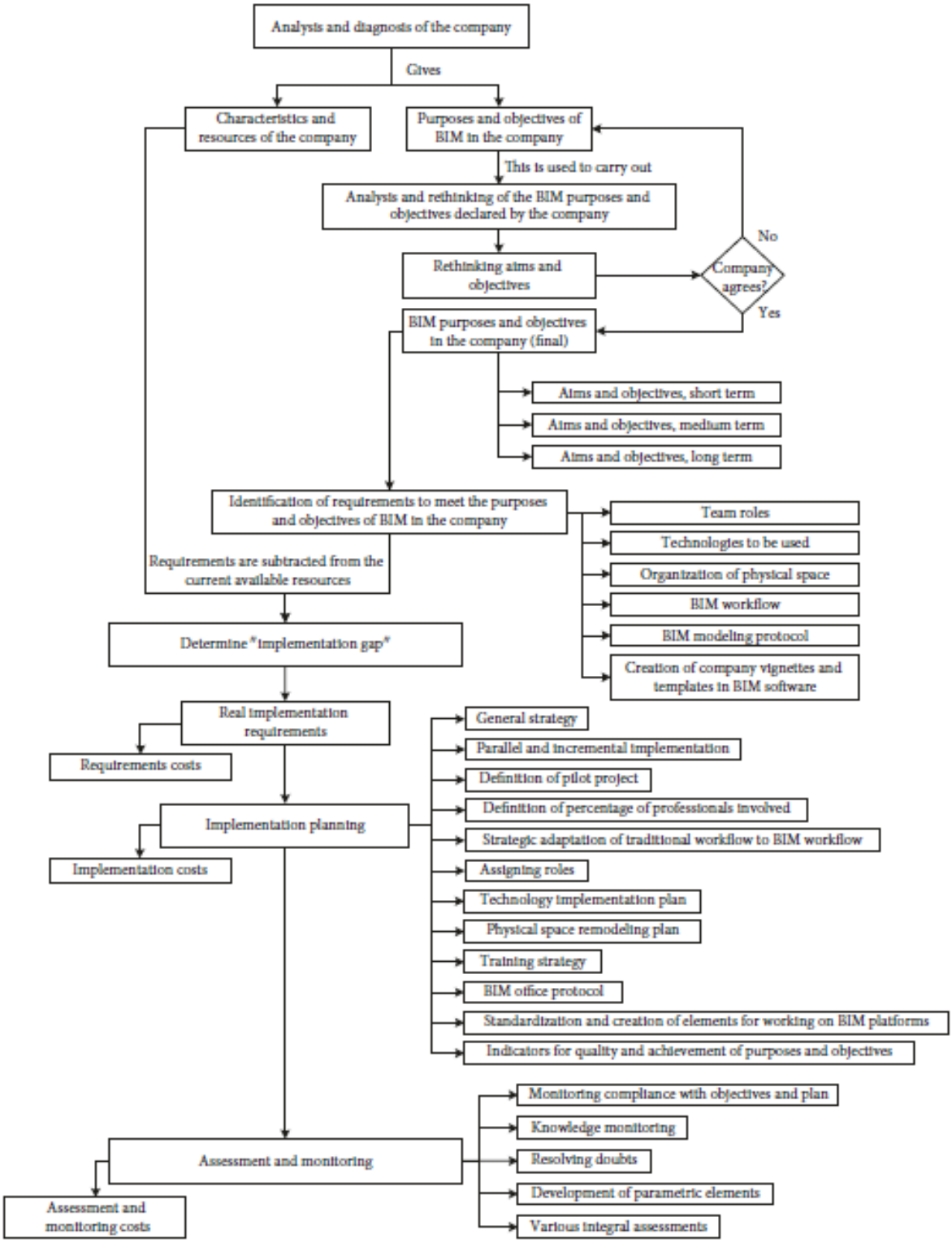
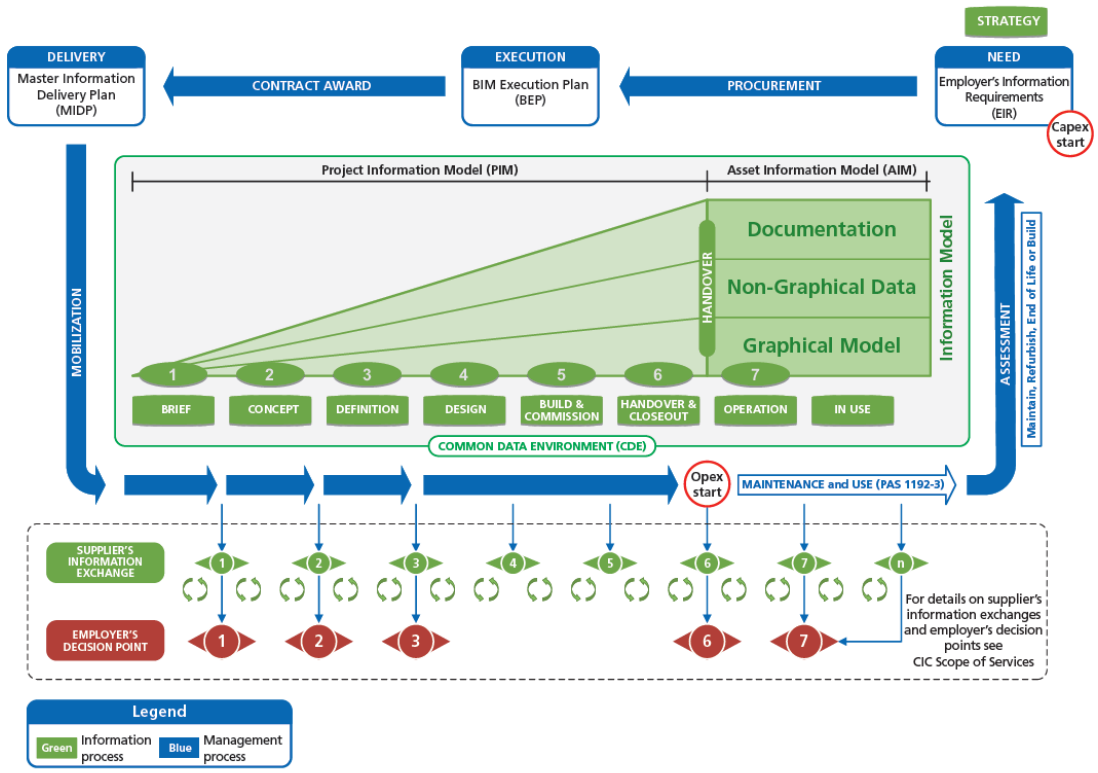
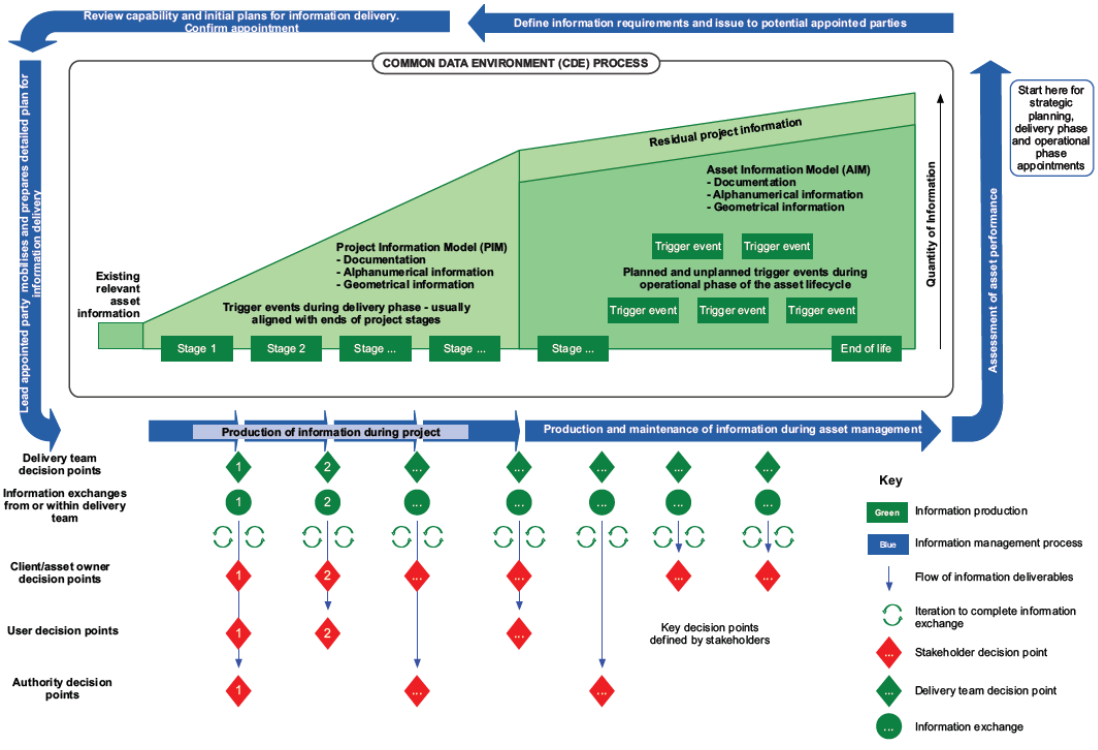


Figure 5: Illustrates the usage of BIM data over the built asset life-cycle process.[8]



a) PAS 1192-2:2013, Figure 2



b) BS EN ISO 19650-1:2019, Figure 1

Figure 6: Illustrates the rapid acceleration in R&D for new digitalization techniques within the AEC Industry.[43]

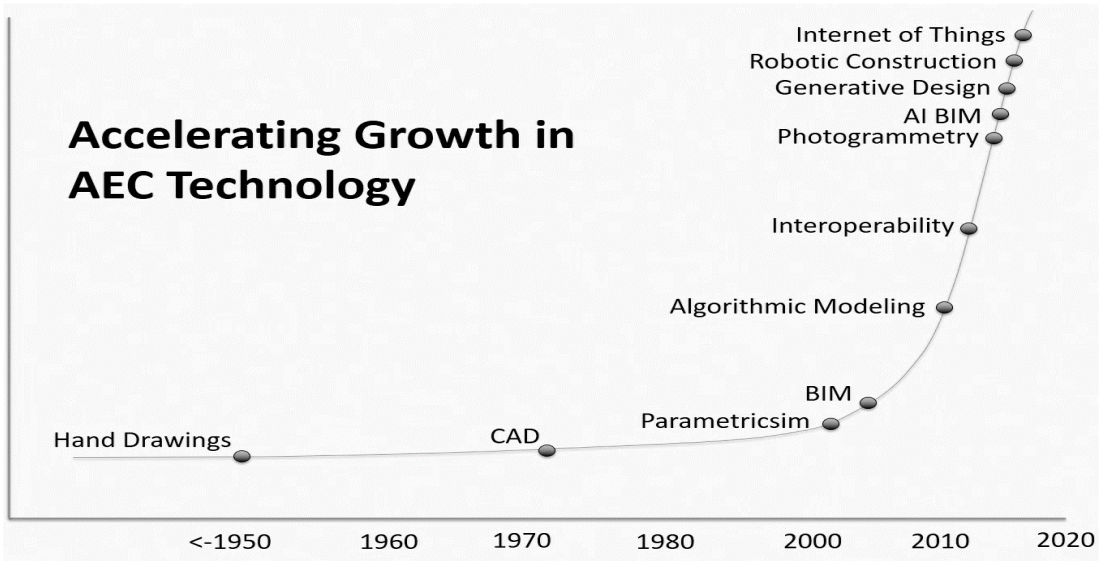


Figure 7: Illustrates the varying levels of BIM within the industry.[15]