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A Conceptual Framework for effective BIM-enabled Information Management in Railways

Vikas Singhal

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Universidade do Minho
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# A Conceptual Framework for effective BIM-enabled Information Management in Railways

BIM A+ European Master in Building Information Modelling

Master Dissertation
European Master in Building Information Modelling

Work conducted under supervision of:
**Jose Carlos Lino**
**Isabel Valente**

Co-funded by the Erasmus+ Programme of the European Union

July, 2020

# AUTHORSHIP RIGHTS AND CONDITIONS OF USE OF THE WORK BY THIRD PARTIES

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# STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Vikas Singhal

# RESUMO


**Enquadramento Conceptual para uma efetiva Gestão da Informação BIM em Ferrovias**

Os projetos de transporte ferroviário estão na primeira linha de qualquer agenda estratégica, uma vez que as vantagens que deles resultam, tais como a sustentabilidade ambiental, os benefícios económicos e o aumento da segurança do transporte para os passageiros, estão já bem investigadas e comprovadas. É também importante que os métodos e processos do BIM sejam aplicados aos projetos relacionados com o caminho-de-ferro, para que os executores do projeto o entreguem sem exceder os prazos e os custos. Há já muitos exemplos referenciados, em todo o mundo, para mostrar as vantagens que os grandes projetos ferroviários atingem, ao longo das diversas fases do ciclo de vida do projeto, ao adotarem processos BIM.

Existem, porém, deficiências na adoção do BIM ao longo da cadeia de fornecimento, nos projetos ferroviários, dado o enorme ecossistema e múltiplos e heterogéneos participantes. Assim, é essencial compreender as necessidades das partes interessadas e os seus requisitos em termos de Informação, para poder utilizar cabalmente as funções de gestão da informação utilizando as tecnologias e métodos BIM. A integração da cadeia de fornecimento e a transição adequada da informação ao longo das diversas fases do projeto são chave para o completo desenvolvimento de uma estrutura BIM e para uma gestão eficaz da informação em todo o projeto.

Este trabalho visa contribuir para uma clarificação do fluxo da informação e da importância de cada uma das ferramentas utilizadas para a sua gestão, através da definição de alguns enquadramentos conceptuais.

O Ambiente Comum de Dados é analisado, enquanto ferramenta poderosa para a gestão, desenvolvimento, disseminação e arquivo da informação, para servir como um canal de integração para toda a cadeia de fornecimento. Existem recomendações e enquadramentos normalizados desenvolvidos para apoiar as organizações na definição do CDE de modo a integrar os diferentes intervenientes e atuar como "fonte única da verdade" da informação, para o ecossistema, em qualquer fase do projeto.

Recomenda-se que os requisitos de informação sejam divididos em Requisitos de Informação da Organização, Requisitos de Informação de Ativos, Requisitos de Informação do Projeto e Requisitos de Trocas de Informação. É fundamental que os requisitos sejam definidos com base nos requisitos das utilizações esperadas do BIM, das principais fases do projeto e dos requisitos das partes interessadas. O princípio de explicitar os requisitos de informação logo no processo de contratação, baseia-se em "ter o fim em vista", o que se torna vital sob o ponto de vista das operações e manutenção.

O conceito de Plano de Execução BIM Pré-Contrato e Pós-Contrato é também essencial para se completar o ciclo de aprovisionamento e a avaliação da equipa fornecedora.


Palavras Chave: Plano de Execução BIM (BEP), Modelação da Informação da Construção (BIM), Ambiente Partilhado de Dados (CDE), Requisitos de Trocas de Informação (EIR), Gestão da Informação em Ferrovias.

# ABSTRACT

The rail-based transportation projects are at the first line of any strategic agenda, as the advantages realized from them such as environmental sustainability, economic benefits and the enhanced transportation safety to the passengers are well researched and proven. It is also important that the methods and processes of BIM are applied to the rail-based projects, for the project executors to deliver the project without time and cost overruns. There are many examples cited to show the advantages that major railway projects around the world have accomplished over the different phases of the project life cycle by embracing the BIM processes.

There are impairments in the adoption of BIM across the supply chain in the railway projects, with the huge ecosystem and multiple heterogenous participants. So, it is essential to understand the stakeholder's arrangements and their requirements in terms of Information, to completely utilize the information management functions using BIM technologies and methods. The integration of the supply chain and appropriate information transition across the project phases are the key considerations for the development of a BIM framework for effective information management across the project.

This work aims to contribute to a clarification of the information workflow and the importance of each one of the tools used for its management, throughout the setting up of some conceptual frameworks.

Common Data Environment is analyzed as a powerful tool for the management, development, dissemination, and archiving of information, to serve as an integration channel for the supply chain. There are standard recommendations and frameworks developed to assist the organizations for setting up the CDE that will integrate the different stakeholders and act as the Single source of truth of the information for the ecosystem at any given phase of the project.

The information requirements are recommended to be divided into Organization Information requirements, Asset Information Requirements, Project Information Requirements and Exchange Information Requirements. It is critical that the requirements are defined based on the requirements of expected BIM Uses, Project Phases essentials and stakeholders' requirements. The principle of expressing the information requirements at the procurement process is based on 'keeping end in mind', which is vital from the operations and maintenance perspectives.

The concept of Pre-Contract and Post-Contract BIM Execution Plan are also essential to complete the procurement cycle and the assessment of the delivery team.

Key Words: BIM Execution Plan (BEP), Building Information Modelling (BIM), Common Data Environment (CDE), Exchange Information Requirements (EIR), Information Management in Railways.

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# 1. INTRODUCTION

World Rail survey report forecasts an annual growth of the railway sector of 2.7 % till the year 2023 (Berger, 2016). This growth, accounts for the construction of new projects and upgradations in the existent rail infrastructure. Along with the strong investments, the opportunity for the adoption of digital technologies for the better delivery of the projects also comes to forefront. Building Information Modelling (BIM) technologies and processes can be the potential tools which can assist the railway project executors to face the implementation and Asset Maintenance challenges, thus improving the project performances and productivity. The experience of the railways projects by integrating the BIM processes, presents several advantages like stakeholder collaboration, time saving, cost optimization, timely conflict resolution, virtual construction scheduling, optimization of asset management, improvement of the quality of works, prefabrication, visualization , design integration process, internal project team communication, collision detection to eliminate risk of rehabilitation, decision support, avoidance of extra work due to design errors, among others (Bensalah et al., 2018a).

One of the biggest challenges to fully adopt BIM, as realized by the railway authorities, is the management and integration of big supply chain and the number of stakeholders involved in the project process. It is critical that the authorities take the opportunities presented by the BIM technologies to enable collaborative environment in the ecosystem, as the implementation of Common Data Environment, to support the design and information workflows (Saha & Raj E, 2018).

The understanding of the information requirements of the Employer, is significant to exercise even before the beginning of the procurement cycle. Requirements management is a fundamental block of the science of Information Management. Exchange Information Requirements (EIR) and Asset Information requirements (AIR) are the core of the requirements which are essential to be given to the prospective suppliers. EIR's presents opportunity to the Employers to detail out their requirements in three broad categories which are, Commercial, Managerial and Technical, information requirements. Employer requirements need to be developed systematically, as per the international frame works, and appropriately be disseminated to all the project stakeholders, which should discover the information requirements, for each project phase, from concept to the Asset management and also based on stakeholders' arrangements (Hafeez et al, 2015). Along with the specification of the requirements, outlining the information delivery planning, standards and methods are equally important (Dearlove, 2020).

The main objective for this dissertation is to propose a conceptual BIM framework which can be specifically applied to the railway sector, by considering all stakeholders in this complex ecosystem.

As a partial goal, the study and clarification of the stakeholder's interaction for a typical railway project ecosystem and the possible workflows Meta data and Information management functions to be followed in the CDE, are also addressed in this work.

Likewise, it´s also aimed the clarification and definition of the Information requirements that are key to ensure that each participant provides or receives the adequate information for the project at each stage, capturing the information transition, throughout the project phases of life cycle, particularly focussing on the information needs of the O&M stage.

As a last partial goal, a practical explanation of this framework for information management over a Metro rail case study, intending to promote an effective use in future cases.

To accomplish these goals, this work starts its methodology research by a broad literature review where the critical analysis of academic and research papers, theses and other trustable sources on the subject allows an understanding of the research done so far about this topic and the possibilities to address the issues in the present dissertation

Particularly, the analysis of specific case studies where BIM was implemented for Railway and Metro are given a special attention on this gathering of knowledge, information and experiences. It´s by studying other practical cases that one´s may anticipate the problems, pitfalls and challenges that this type of implementation has been raised. A review of stakeholder management principles and different possible ways of analysing the information requirements from stakeholder's perspective will be proposed.

A proposal over the most appropriate use and vital considerations while implementing CDEs in a railway project environment will be reviewed. Also, analysis of the challenges with the Information management in a complex ecosystem, which are often represented with multiple interfaces will be presented.

Review of importance of Information requirements and information delivery planning. The recommendation about standardization of the process of information requirements, with the details of the concepts of Exchange Information Requirements and BEP is presented.

Lastly the study of the BIM framework in a Metro or rail company is presented, in order to validate and enhance the work and to explore the level of BIM implementation that could be useful and practical to the railway sector.

So, to structure the presentation of this work, this dissertation is organized in six chapters starting by this introductory one. This first chapter deals with the introduction of the dissertation, objectives of conducting the research, methodology and organization of the dissertation.

It is followed by the second chapter that entails the literature review on the introduction to the railway projects with focus on the Business & economic value of the railways. Growth prospects of the sector and the cases for the adoption of different aspects of BIM in the railway projects around the world and the benefits realized from the process change. Unlike some other formats of dissertations, it´s important to stand out that, due to the way that the conceptual frameworks are discussed all over this document, it was decided to spread the literature review all over this dissertation, instead of framing it only in this second chapter, thus, bringing the state of the art for each particular subject, closer to the very chapter where each of main parts on this Information Management Process are addressed.

The third chapter analysis the railway ecosystem and explores the different stakeholder arrangements and some possible information requirement lenses within the ecosystem. The concept of Common Data Environment in large scale infrastructure has been reviewed in detail to establish the integration of the big supply chain using recommendations of the International standards and possible customizable workflows.

On the fourth chapter, the importance of Information requirements in the process of Information management has been reviewed in the chapter. Different elements of information requirements and the structure of a prospective Exchange information requirements are delved into based on the guidance from the ISO and PAS standards.

The fifth chapter presents a case study on the implementation of BIM at Maharashtra Metro Rail Corporation in India. The intent is to provide actual railway experience where this specific framework may be adopted, with success, for achieving the BIM objectives for the Metro railways.

As a sixth and closing chapter, conclusions about the achievements of this work will be provided, as well as suggestions for future developments.

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# 2. RAILWAY PROJECTS AND BIM ADOPTION BENEFITS

## 2.1. Introduction to Railways

Railway is one of the veterans, mature and established engineering sector. The railway projects represent a critical backbone for the mobility of the people and the cargo, which is vital for the economy of the state and the country.

The world rail market study seventh edition (Berger, 2016) provides the view and the analysis of the present status and expected development of the total world rail supply market with the forecast till the year 2023. The study presents the market of 60 countries, which jointly comprise more than 98% of global rail traffic, divided into seven regions.

The significant investments by the operators in the services, infrastructure, and rail control, has led the rail supply market grown by 1.2 % per year from the 2013-2015 period to the 2015-2017 period and now has a volume of EUR 163.2 bn. The projection forecasted by the study shows that the rail market should grow by an annual rate of 2.7% until 2023, when the annual volume is expected to reach approximately EUR 192 bn. As per the study, the key drivers for this positive rail market development are from the operator's point of view, consistently investing in upkeep and extension of their infrastructure and rolling stock bases. Also, upgrades and modernisations of signalling systems will further drive the market in established rail regions. In addition, emerging rail markets, such as Africa, Middle East or Latin America, will contribute to market development through continued development of their infrastructure and rail systems.

Smith mentions that the infrastructure sector values 7% of UK gross domestic product (GDP) or £110 billion *per annum* of expenditure, 40% of this being in the public sector, with central government being the industry's biggest customer (Smith, 2017). If the value of design, manufacture, assembly, construction and commissioning of built facilities through to their subsequent operation, maintenance, refurbishment, deconstruction and reuse is considered, the sector accounts for almost 20% of GDP.

According to Bensalah *et al.*, Rail is considered as vial infrastructure industry for economic and regional development at country level which drives huge public investments (Bensalah et al., 2018a). It contributes greatly to economic growth and human exchanges. Some of the benefits of the railways whether Mainline, cargo or urban trains are the following; Addressing the transport Safety Concern, the train represents a solution to reduce the human and property casualties due to road accident in the urban areas and the highways. On the Optimization of Space, Urban railways like Metro and trams are essential to decongest the traffic woes and provides connectivity with the economically vital areas with the urban centres and residential areas. Also, it should be noted that a double rail track requires 14 m against 40 m for highway. Addressing Environment considerations and carbon footprints, rail transport is one of the greenest modes of mass public transportation today. It helps in the reduction of greenhouse gas emissions, in the reduction of energy pressure and increasing the safeness of dangerous goods transport solutions, all of them vital for the authorities. Rail also has an unrivalled ability to drive growth and regeneration.

Still accordingly to the same authors (Bensalah et al., 2018a), the Railway sector will surely experience major infrastructure development and renovations in the near future all around the world, but it faces, like any other AEC industry, significant constraints in terms of reduction in cost for better appreciation of public investments and delivering the projects within anticipated time and quality. As stated by Suchocki, the railway projects are long time commitments and include several phases from the planning, construction to subsequent operation and maintenance (Suchocki, 2017). Throughout these different phases, multiple stakeholders exchange thousands of documents and drawings. Studies also imply that many project activities are sequential, and the project essential collaboration remains difficult between the different disciplines and it leads to more error probabilities, thus, resulting in time and cost overruns. Still according to Suchocki, some of the problems associated with the supply chain in Railways are: The different phases of the projects, along with the information integration among them, is being misunderstood by the ecosystem; the individual stakeholders are normally engaged with the improvements in the specific process, based in their contractual arrangements and obligations, but without realizing the wider workflow to determine if a larger scale change across multiple phases and disciplines can deliver more significant benefits.

In the era of advancement in the digitalisation in the AEC industry, railway sector must be prepared to carry out process changes to stay more competitive and offer better return on investment. For the transformation of the construction industry, adoption of digital technology and modern construction techniques, would be the key factor. There are many standardised methods available in nowadays, but the platforms that better integrate most of them, aiming to transform the construction industry usually rely on utilising Building Information Modelling (Yean, 2018).

## 2.2. BIM Adoption Benefits in Railways

To achieve this approach of transforming the construction industry in railways, should be to integrate the Building Information Modelling technologies, standards and processes throughout the life cycle of, which has potential to address the typical infrastructure project constraints. Sabol explains that the BIM technologies facilitates the integration of the roles of all stakeholders on a project and are a new potential dominating paradigm within AEC industry. BIM is a technological and process management tool that offers a platform for enhanced collaboration, change management and information support throughout the building lifecycle (Sabol, 2008).

Though the benefits of the adoption of BIM in the project sphere are immense, Suchocki explores certain inherent drawback in the railways which are limiting the adoption of BIM: The participants involved have recognised the opportunity BIM presents to improve specific activities rather than the benefits which BIM processes delivers for the collaboration of the whole ecosystem; Relatively mature workforce and perceived lack of innovation discourage new entrants. The age profile of this industry workforce, includes many employees who are in the late stages of their careers (~24% over 50); Standard practice and reliance on the legacy safety cases can be used as an excuse to avoid change in the processes or invest in innovation (Suchocki, 2017).

This same author mentions that the use of BIM for the Railways projects is significant during the planning and conceptualization phases. BIM technologies along with augmented use of existing asset data, geospatial information, laser and photogrammetric scan data with the ground survey information, has the potential of supporting the requirements of understanding the as-is environment. It states the importance of BIM technologies for the underground utilities interface management and use of generative designs for effective decision making about the selection of rail alignment along with the associated path structures

Illustrating this, Bensalah explored the BIM uses in five selected rail projects; Malarban project of Swedish Transport Authority (Sweden), Railway SNCF maintenance France (regions of Metz and Strasbourg and the catenaries in the framework of the Charles de Gaulle Express project - France), Cross-Rail (Elisabeth Line-London, U.K.), ONCF 40 electrical substations (Morocco) and Schuman–Josaphat Tunnel (Belgium) (Bensalah et all, 2018b). Following is the table summarizing the benefits realized by the projects with the adoption of BIM.

**Table 1- Benefits of BIM adoption in railway projects (Bensalah et all, 2018b)**

| Project | Benefits |
| --- | --- |
| Malarban project | Benefits realized in the concept design phase including the supported design feasibilities, design collaboration challenges, improved design quality, adoption of Integrated project delivery, accurate cost estimation and its change management throughout the design phase. Construction sequencing and simulation (4D) with encouragement to the lean construction. Improvement in the Operations and Maintenance with integration of 3D elements and better visualization of the placement of objects. Quantity take offs and information reuse for the different phases of the railway project. The overall result is better achieved quality, savings in the time and cost. |
| Railway SNCF maintenance | The objective was to enable an effective Maintenance system. BIM was used for the signalling, traction, track and station maintenance purposes. The benefits were improved awareness about the network performance in terms of economic values for both existing and new projects. |
| Cross-Rail | The organization observed 25 % decrease in the rework and waste. Direct fabrication from BIM |

| | |
|---|---|
| | resulted in significant reduction in errors and improvements in the time overrun for the project. |
| ONCF | BIM was used for the construction of electrical substations as part of the railway project. It enhanced the design collaboration among different task teams. Time savings, cost optimization, conflict prevention and resolution, building a virtual space before actual construction, facility management optimization, prefabrication and better achieved quality. |
| Schuman–Josaphat Tunnel | Better integrated designs, established communication protocols to improve inefficiencies caused by mis communications. Collison detection and avoidance of rework, higher quality of the project delivery without time and cost overrun. |

Pointing towards similar conclusions, Mbiti studied and analysed the factors influencing effective implementation in Mega infrastructure projects and confirmed that BIM Technology has a positive effect namely on the implementation of Standard Gauge Railway project in Kenya. The study findings revealed that BIM technology had a positive and statistically significant effect on Effective Implementation of SGR project (Mbiti, 2018).

Also, Tviet and Gjerde, explain how BIM processes and technology was successfully used as an integrated part of the master planning process for the 30 km Sorli-to-Brumunddal high-speed rail project in Norway. The paper concludes that new enabling technologies, cloud-based services and BIM collaboration tools can drastically enhance the way complex multi-disciplinary infrastructure projects can be planned, designed and implemented (Tviet and Gjerde, 2018). Important goals and achievements for using BIM in the planning phase of the high-speed project are: Improved communication performance by using the information model across the process; Enhanced output quality through inter-disciplinary coordination; Lesser requirements of drawing led to reduction in the project cost and focus on entirety and Use of Information Models for reliability and safety parameters.

So, despite all the particularities, local conditions, and cultural differences, a conclusion rise from the study of the multiple examples analysed on the literature review above presented: the adoption of BIM methods and technologies, by many organizations, in all phases of the railway project, clearly leads to effective and quantifiable benefits.

# 3. RAILWAY ECOSYSTEM AND THE ADOPTION OF CDE

## 3.1. Railway Ecosystem

A study about the big and complex railway ecosystem necessarily needs to present the interaction among different stakeholders at different stages of the project. Similar studies about the supply chain and all the stakeholders have already illustrated the complexity of the whole process and mechanism.

Smith mentions that the central London section project work being delivered by Cross-Rail is highly complex with over 25 design contracts, 30 advanced works and 60 construction and logistics contracts, often with many discipline interfaces. It makes the whole project process vulnerable to the problems of miscommunications and collaboration issues. The potential risk carried along with the huge ecosystem, must be meticulously managed by the authority by creating and enabling contractual control based on a reinforced administrative environment. The collaborative nature of BIM is viewed by Cross-Rail as an important way to manage this risk (Smith, 2014).

Taylor also mentions that Design management, Construction and the process of handover for the Operations & Maintenance of the Elizabeth line of the Cross-Rail project is an example of a highly complicated programme of projects to manage, which is evidenced by the contractual and stakeholder arrangements required to deliver the railways systems and infrastructure. With 23 framework design contracts and 83 construction and logistics contracts, the issues pertaining to use of not correct or up to dated information may cause serious implications in the interface management and may lead to reworks and time & cost overruns for the project. Along with the huge scale of the railway project, the significant risks are associated with the nature of different disciplines which are very distinct, including the systems at stations, along the track alignment, in the Rail Depot or at the Operational Control Centre (Taylor, 2017). Most railway projects move into their operational phase with one O&M organisation. However, the Elizabeth line will be operated by Rail for London and have infrastructure maintained by Network Rail, Rail for London and London Underground Limited. The scenario of multiple operations and maintenance stakeholders for the Railway project represents further complexity in the information delivery during the handover stage.

Tveit and Gjerde explore one of the significant implementation challenges that is the planning process of the high-speed railways. When the project ecosystem has many stakeholders that have different roles they are either to be involved or to exchange information about the process. A preparation of thorough compliance and responsibility plan was essential to ensure a efficient information flow and involvement of the critical stakeholders (Tveit & Gjerde, 2018).

### 3.1.1. Stakeholders Management and definition

From the above case studies, it can be well understood that it is essential that the information and data requirements are identified early in the project which has to be based on the people, departments and organizations that could impact the project process. PMBOK (Project Management Book of Knowledge) identifies four step processes for successful stakeholder management, which is very relevant for adopting the BIM strategy in big ecosystem. Making a similar link with Stakeholders Management on a BIM Implementation we might connect those four phases to Identification of Information Exchange Parties, stakeholder engagement through business processes , management of stakeholder engagement by implementing appropriate technical solution and monitoring the engagement by regular audit of the defined processes and workflows, as we may see in the Figure below.

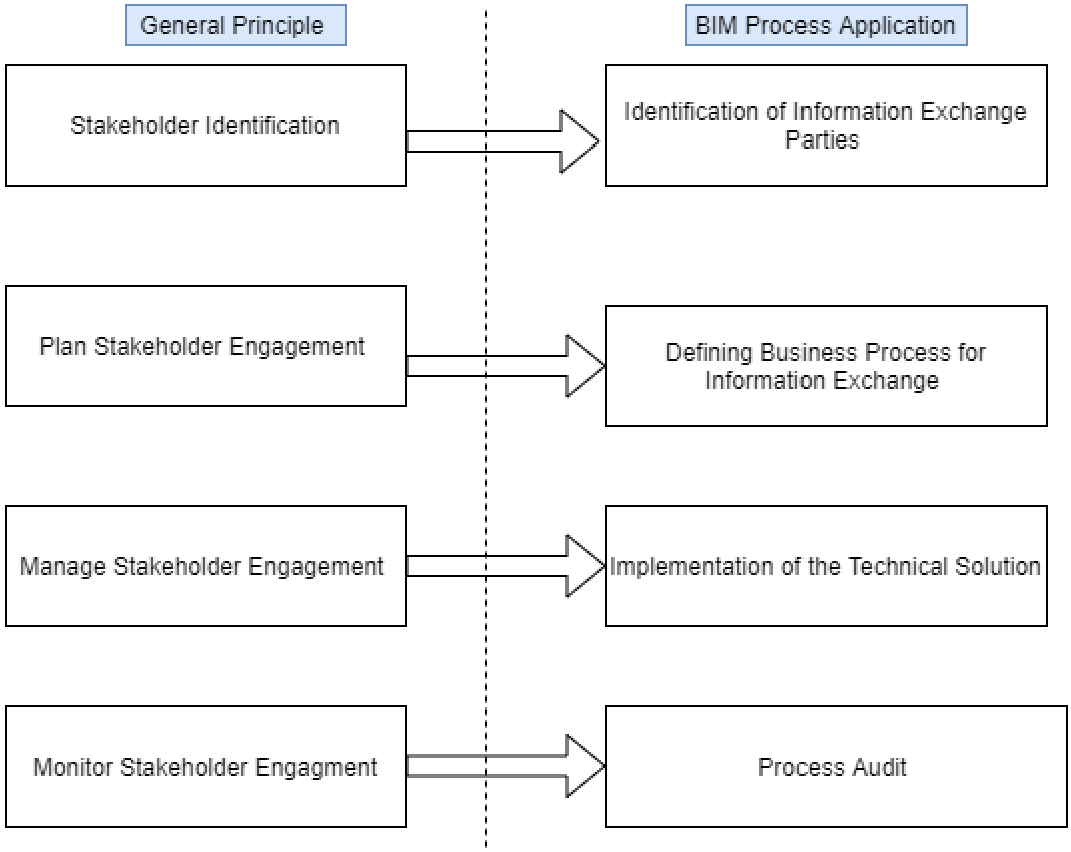



**Figure 1 - Stakeholder Management Process: PMBOK link with BIM Process (General Principles Adopted from PMBOK, 2013)**

The stakeholders are those who have contractual obligations, whose relationship to the project is derived from their ability to affect the project work, organization or other stakeholders (Kolesnikov, 2014).

It is essential to understand the roles and relationships of different stakeholders in the project ecosystem. The understanding of the definitions for the stakeholders in a typical ecosystem are critical in view of ascertaining the arrangements and their interactions, which is fundamental to draw the information needs and subsequent information management.

The definition for some of the critical stakeholders from General conditions of the EPC contract by FIDIC (International Federation of Consulting Engineers), first edition 1999 are as follows:

- "Employer"- means the person named as employer in the Contract Agreement and the legal successors in title to this person;
- "Employer's Representative" means the person named by the Employer in the Contract or appointed from time to time by the Employer under [The Employer's Representative], who acts on behalf of the Employer;

- "Contractor's Personnel" means the Contractor's Representative and all personnel whom the Contractor utilises on site, who may include the staff, labour and other employees of the Contractor and of each Subcontractor; and any other personnel assisting the Contractor in the execution of the Works;

- "Subcontractor" means any person named in the Contract as a subcontractor, or any person appointed as a subcontractor, for a part of the Works, and the legal successors in title to each of these persons.

ISO 19650-1: 2018, on a broader classification, also present a definition of the key stakeholders' terminologies as presented in the following Table.

**Table 2 - Stakeholders definition as per ISO (ISO 19650-1, 2018)**

| | |
|---|---|
| Appointing party | The organisation leading the project or asset management. For a project this is typically the client, who may also be the asset owner |
| Lead appointed party | The party who is responsible for co-ordinating information exchange between task teams or between a delivery team and the appointing party |
| Appointed party | Anyone generating information about the project – for example a contractor, sub-contractor, supplier, consultant |
| Project team | Everyone involved in the project, regardless of appointment/contract arrangement |
| Delivery team | A lead appointed party and their associated task teams - a contractor and its sub- contractors and suppliers for example |
| Task team | A person or group of people performing a specific task – for example the architecture team or the sub-contractor who is designing/constructing curtain walling |

### 3.1.2. Stakeholders Information Requirements Filters

Lenses and filters may act as an analyse and investigative tools which can be used to understand the underlying concepts and relations (The BIM framework blog, 2015). Applying the information filters systematically can increase the efficiency of the information management process. This work presents some possible filters as per the information requirements in a complex ecosystem that can be applied to a typical railway ecosystem, as shown in the figure below.

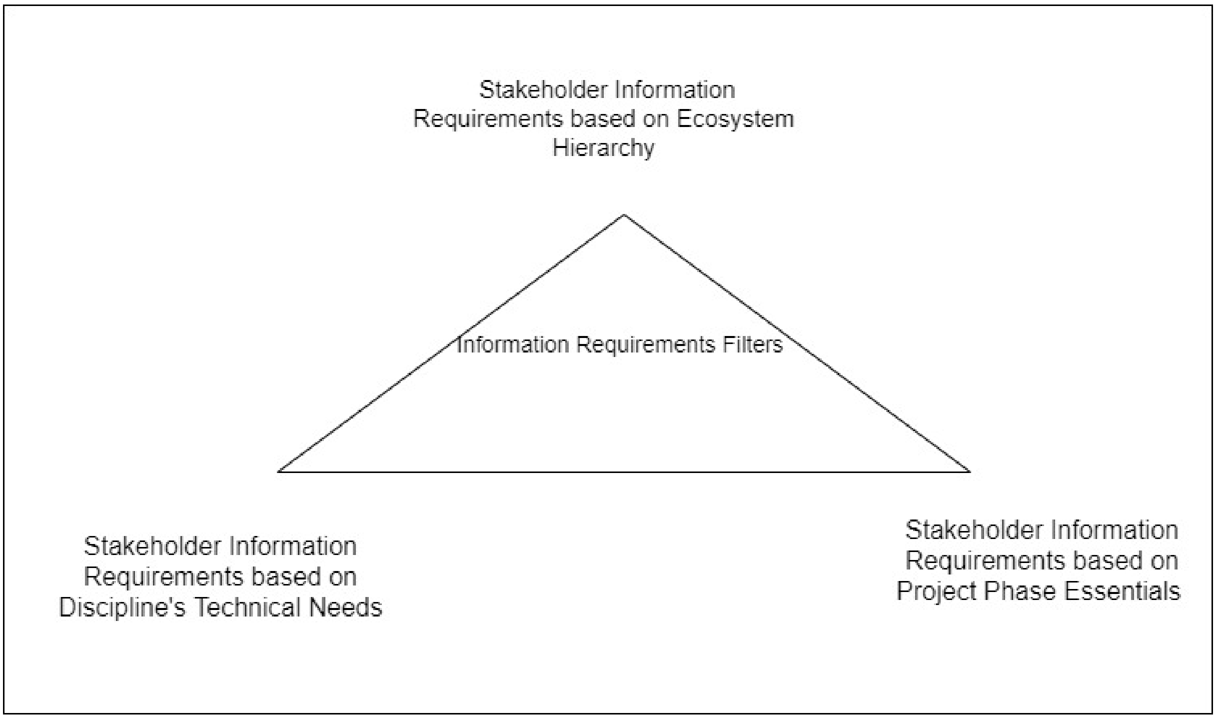



**Figure 2 - Information Filters for Stakeholders Information Requirements**

Below is the description of the some of the possible Information filters for stakeholders as shown in the figure above:

**Based on a possible Ecosystem hierarchy**

This filter of viewing the stakeholder engagement based on the ecosystem hierarchy is important for understanding the roles and responsibilities of the engaging parties, this also entails the authoring, reviewing and approving environment for the information artifacts.

Eastman defines the contract types and stakeholder engagement as described on the Figure below (Eastman et all, 2011):

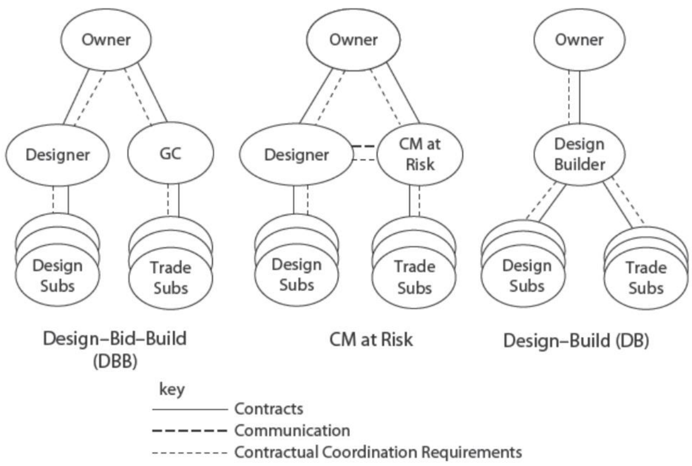



**Figure 3 - Schematic Diagram of Design-Bid-Build, Contract Management at Risk and Design - Build (Eastman et all, 2011)**

This work based on the definitions cited above classify a possible typical railway organization hierarchy. In this Employer and its nominated representatives have project managers, engineers for different disciplines who are responsible for defining the information requirements before the procurement cycle and also carry out the task of reviewing and authorizing the delivered information for further use in the project. Further, there are different procurement and contract arrangements, some of who are as listed in the figure below.

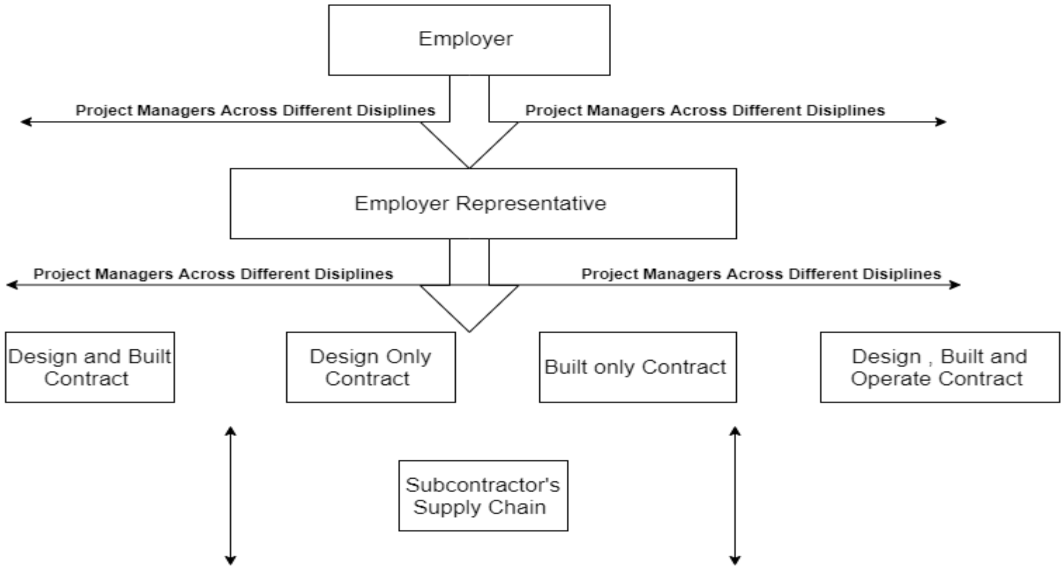



Figure 4 - Stakeholder requirements based on organization hierarchy

**Based on Railway Organisation and Technical Disciplines:**

This classification is essential as Railways is a multidisciplinary ecosystem and each discipline has different and distinct information requirements, some departments use conventional data formats while others support 3D information models. As an example, signalling interlocking and Electrical systems design requires more of 2D circuitry diagrams and other design documentation (Yean, 2018) rather than 3D Models for the design management process, though the information management through Models are essential for the Asset Management or other project related processes.

In the figure below, the requirements are categorised in five main railway domains which are Planning department, Civil infrastructure, System engineering, Administrative departments like procurements, commercial, among others, and O&M. Some of the general roles which are executed by these broad domains are also characterised as below.

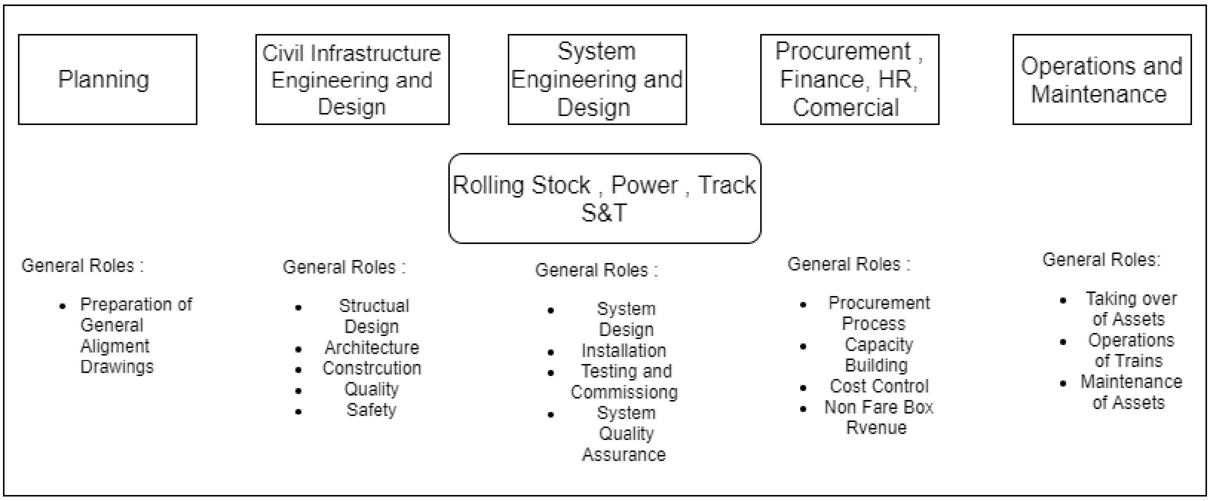



**Figure 5 - Stakeholders requirements based on Technical Disciplines**

**Based on Project Phase Requirements**

The filter based on project phase for the information requirements is essential as different phases of the railway project has different requirements, also it is important to understand how information developed during one phase has to be integrated and needs to be in sync with the subsequent phase's requirements.

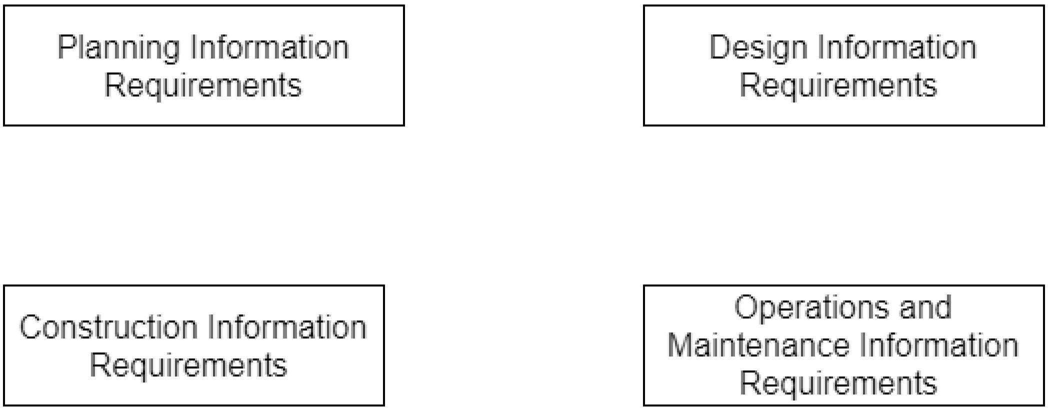



**Figure 6 - Stakeholders requirements based on Project Phase essentials**

In conclusion, the illustration for explaining the above-mentioned information filters can be seen as a stakeholder participating in the process as follows on the next Figure. The figure applies the above described filters, with the selection of step one, based on the ecosystem hierarchy then applying the second filter, to understand what is the technical requirements of the stakeholder based on its discipline and then, finally, which project phase it belongs to.

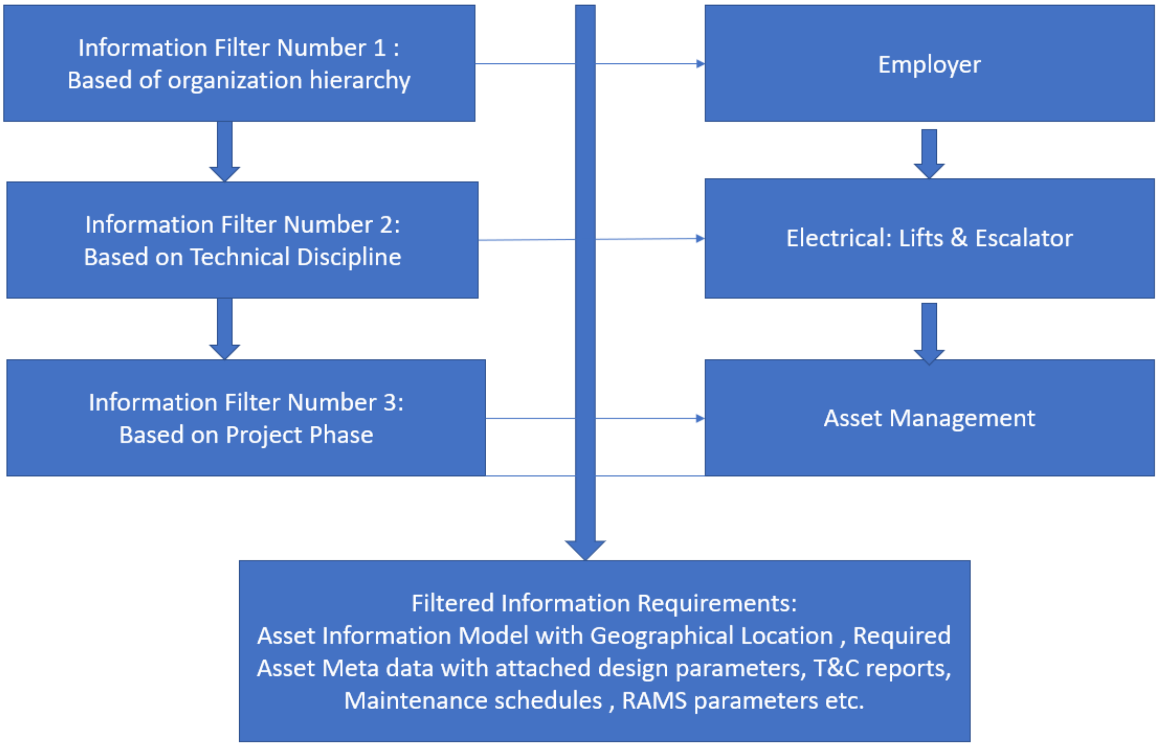



**Figure 7 - Example of a sequence of Information Filters for Stakeholder information management**

## 3.2. CDE as an Ecosystem Integrator

### 3.2.1. Challenges with Information Management

There are challenges with the mega infrastructure project's ecosystem, where multiple teams work parallelly, with multiple interfaces that are often placed at geographically different locations, including the construction sites, design offices, Operations, and Maintenance setups. The management of updated and distributed information data should be based on a single source of truth for all the stakeholders (Zohari Akob et al, 2019). Decision-making based on trusted information quality and the acknowledged source is vital for the project's desired success.

Insufficient Information is the cause of many of the negative impacts on the process of construction projects. Some examples of insufficient Information are deficiencies or faults in the documentations, aberrations from the original scope of the documents, poorly defined scope of documents at the beginning of the process, and ill coordination among stakeholders of the supply chain to produce a piece of integrated Information (Radl & Kaiser, 2020).

The same authors also mention that the information management systems should possess appropriate controls, as the process which has inappropriate controls leads to an increase in the cost, time delay and quality issues with the project. It is also crucial that the control points are managed, so that accurate Information is accessible to the persons involved with the work and the process.

In the analysis of how major infrastructure companies in the UK are implementing the collaborative practices for the production, exchange, and sharing of the Information (Jallow et al, 2019), one of the key findings is the inconsistent information communication protocol among different teams within the organization. The primary issue highlighted was the adoption of different means of the communication of Information by the organization. The above is mainly an unacceptable scenario when the organization needs to create a coordinated result, along with the challenges of heterogeneous working groups

(Saha & Raj E, 2018) mentions that the data in big construction projects are inappropriately structured and lack the required coordination among disciplines. This scenario makes other supply chains aloof with the right Information and is unworkable with the available data, which explicitly affects the construction cost and the unstructured Information, resulting in a 20 to 25 percent increase in the overall cost of the project. The Common Data Environment (CDE) is a solution to this widespread and common complication of construction projects.

The acknowledgment and implementation of the information system, which can support the origination, distribution, and archiving of the coordinated and integrated project information, needs to be considered, enabling effective information use independent of stakeholder arrangement in the procurement process. Within such a collaborative environment, different teams have to agree on the collective and shared standards, procedures, and drop points to produce the Information which can be used or reused efficiently across the whole Ecosystem for the project lifecycle.

### 3.2.2. What is the CDE?

British Standard Institution (BSI) describes the Common Data Environment (CDE) as a

> "Single source of Information for any given project or asset used to collect, manage and disseminate all relevant approved files, documents, and data for multidisciplinary teams in a managed process (PAS 1192-3)."

Importantly, it defines Information Delivery Process as CDE. The CDE is a means of providing a collaborative environment and can be implemented in different ways as per the requirements of the organization and project structures.

ISO states that the management of Information during Asset maintenance or earlier project delivery phase shall be based on the technical CDE solution and the defined workflows for processes management. It defines the transition of the Project Information Model to Asset Information Model, using the information containers identified for the Asset Management and others for the archiving purpose. It defines CDE as an

> "agreed source of information for any given project or asset for collecting, managing and dissemination each information container through a managed process (ISO– 19650:1, 2018)."

The Common Data Environment can also be explained as the common digital space for the project stakeholders with the well-assigned access work areas for the different disciples, work delivery statuses and end to end workflows for the reviewing and authorization of information artifacts (Periled et all, 2016). This definition explores three key aspects of a prospective solution of CDE: (1) a digital platform which has to be used by all participants within their access rights in the ecosystem hierarchy; (2) the platform should be able to represent the status or stage of the work and (3) the support to define the customized and robust processes which are required for the reviewing, commenting or approving actions in the complete design review process.

McPartland further explores that the CDE contents are not limited to the Information created in the BIM environment but also extends to other project information, including documentation, graphical models, and non-graphical data generated during the execution of the project life cycle. This definition is particularly crucial for the Railway projects where System engineering departments like Rolling stocks, Traction, signalling etc. are dominant and, at present, mostly represent data in the conventional data formats. These systems are critical for the operations of trains and contribute at large in the Asset valuation and the infrastructure maintenance (McPartland, 2016).

### 3.2.3. Advantages of CDE

PAS 1192-2 identifies the advantages of a well-established CDE as follows:

- The issue for the change management can be addressed as the ownership of the data remains with the originator, and any required change can be managed along with the originator of the Information. It also establishes clear ownership of the Information. On the other hand, it is also easier to identify or establish the roles and responsibilities for creating the RACI matrix;
- Digital sharing of Information reduces the time and cost, as it persisted in the traditional and conventional paper or file-based approaches;
- With consistent use of procedures for the sharing Information, spatial coordination is a by-product. It results in the delivery of correctly coordinated Information for the first time, and this helps reduce the time and cost by eliminating the constant iterative processes;
- Enables the use of Information for design, planning, cost estimation, construction, operations, and maintenance, covering the project life cycle use of the Information;
- Data within a CDE is finely granulated and structured to ease its reuse. It provides the ability to produce traditional drawings or documents as views of multi-authored data within the CDE;
- CDE provides better control over the management of metadata of the Information, ensuring revision and version management;
- It enhanced the principle of collaboration in the Ecosystem through the strict adherence of the established standards and protocols for the information exchange, unlike the non-structured way of working.

Zohari and others mention the improvement and quantitatively measurable RoI (Return on Investment) with factors such as enhanced searching and access capability to the project information. Also, a well-established CDE helps mitigate risk by enabling a single source of truth for project participants and providing the correct quantification of the performance of the supply chain as per contractual deliverable plans (Zohari Akob et al, 2019).

With the above review and explanations, the benefits of setting up Common Data Environment for Mega infrastructure projects as per the standards are quite evident. A well-ingrained CDE promotes a collaborative working culture within diverse teams and could be the most critical factor for the

Integrated Project Delivery. CDE standardizes the communication protocol within the team and outside stakeholders, this is imminent for integrating or streamlining the complex Ecosystem like railway projects.

The guidance from ISO 19650 and PAS 1192 series of standards, emphasis on the life cycle management of Information through the appropriate transition between capital delivery phase as Project Information Model to Asset Management Phase as Asset Information Model, using CDE.

As shown in the previous section 3.1.2 about the information needs for the different stakeholders, it is significant that the Information concerning the specific phases and disciplines are identified within the Information Container for the respective information Models (ISO -19650-1). Thus, Figure (2) can further be extended, as shown on the Figure below:

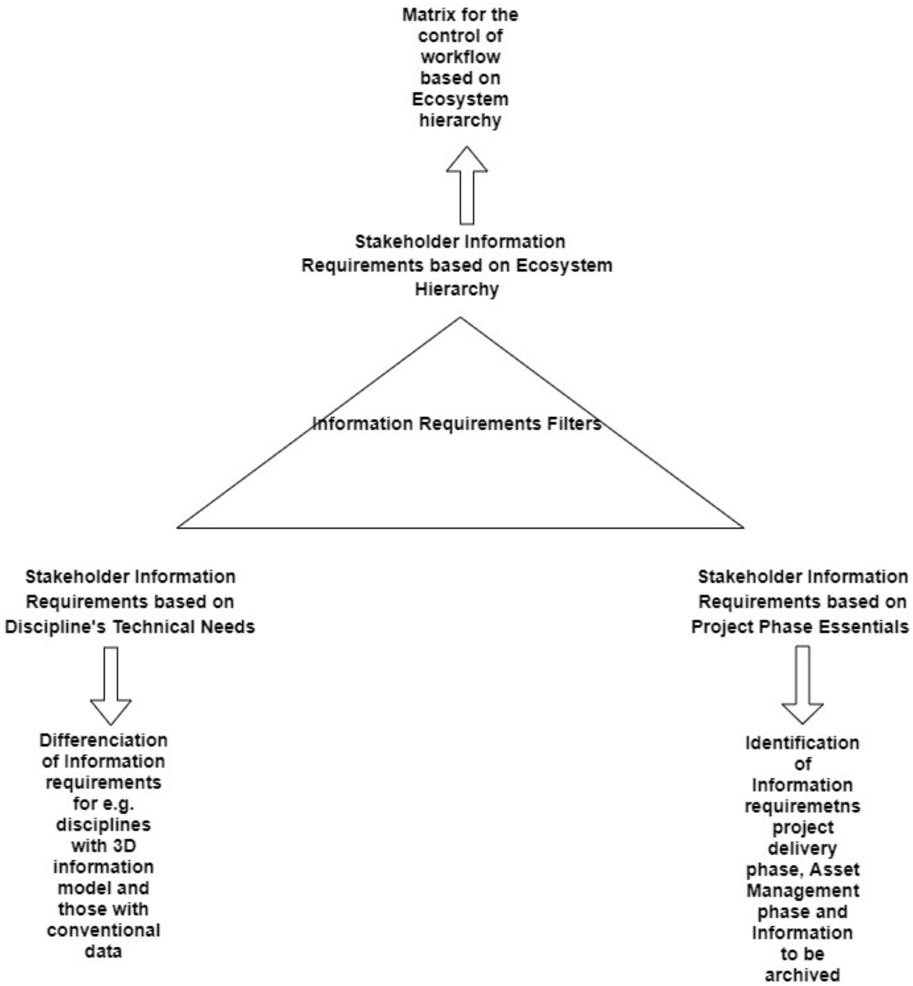



**Figure 8 - Information Requirements/Filters Equivalence with CDE**

### 3.2.4. Cases on the Adoption of CDE in Large Infrastructure Project

**Cross-Rail, UK**

Smith (Smith, 2014) and Taylor (Taylor, 2017), explores the utilization of Common Data Environment for the execution of the Cross-Rail project. Its emphasis lays on the advantages of using CDE for the overall project management of the project. It highlights that one of the essential characteristics for the adoption of BIM is the creation of CDE, explicitly covering the information exchange requirements and promotion of the use of standardized structured Information throughout the life cycle of the project and for all project participants.

Cross-Rail, as in the role of client and employer enabled information management through CDE, and it encompasses the setting of standards and protocols in which all parties involved in the project process are required to be followed. *Cross-Rail's approach to collaborative working was a major component of establishing the first BS 1192:2007 common data environment (CDE) (BSI, 2007).*

The CDE was the single digital common space for the creation of project information, which then could be managed and distributed with the multidisciplinary teams.

**MLRT Line 2 Project and Pan Borneo Highway, Malaysia**

Several authors mention the successful implementation of CDE at the organization level for MLRT Line 2 project in Malaysia (Zohari Akob et al 2019). The objective was the part of the strategy to implement BIM standards, establish digital workflows, encourage design collaborations and ensure the as-built quality standard for the infrastructure of the underground line along the Klang Valley.

A similar strategy was adopted for the construction, development, and up-gradation of Pan Borneo Highway in the state of Sarawak. *Costing RM 16.5 billion, Pan Borneo Highway Sarawak is deemed the largest infrastructure project ever awarded by the Government in Sarawak. Implementation of the project involves the construction of 786 km of a new 4-lane highway in 11 works packages.*

CDE enabled the project management company to:

- Consolidate in a single space the Information in different formats like BIM, GIS and conventional;
- Structure the Information from geographically distributed places;
- Control the workflows with multidisciplinary teams;
- Generate of audit trails to enforce controls over the processes;
- Progress dashboards to all stakeholders, to provide better visualization of the project status;
- Facilitate Project information transition to the asset lifecycle management.

Importantly, the envisaged CDE was not a simple electronic document storage system but a digital platform based on BS 1192 standard series.

### 3.2.5. What should be the structure of CDE? (ISO 19650 perspective)

UK BIM Framework in its Guidance for Process for Project Delivery, in the discussion for the structure of Common Data Environment (Ford & Try, 2020), first describes two different types of CDEs as Project and Distributed CDE. The Project CDE is provided by the appointing party (Employer) or the third party on behalf of the appointing party, for the information management during the life cycle of the project. The delivery teams may also have their own distributed CDEs, but this should not replace the Project CDE.

This section will explore the concepts regarding the envisaged components and the structure of CDE as per standards and the various international frameworks guidance.

The basic unit for information management is the Concept of Information Container (ISO 19650 -1, clause 3.3.12). It is defined as the persistent set of Information, retrievable from within the file, system, or application storage hierarchy. This may include subdirectory, types of information files like Models, documents, schedules, etc. The clause characterizes the information container into structured and unstructured information. Structured information containers contain geometric models, schedules, and databases, while unstructured containers contain other documentation, video clips, etc. Emphasis has been given to the persistent use and the management of the Information over the defined project life cycle. In other terms, Information container is a way for the unique identification of a file. This information container (file) can include a construction schedule, 2D drawings, 3D Models or an asset artifact, so, any digital information about the Built environment. This digital Information has to be created and managed for the project on the established CDE.

ISO 19650 (1) clause 3.3.8 further develops the concept of Information Model, which is a set of structured and unstructured information containers**.** An Information Model is not only a geometric model but a collection of different information containers. It emphasizes that the information containers are created, organized, and managed based on standards rules and protocols.

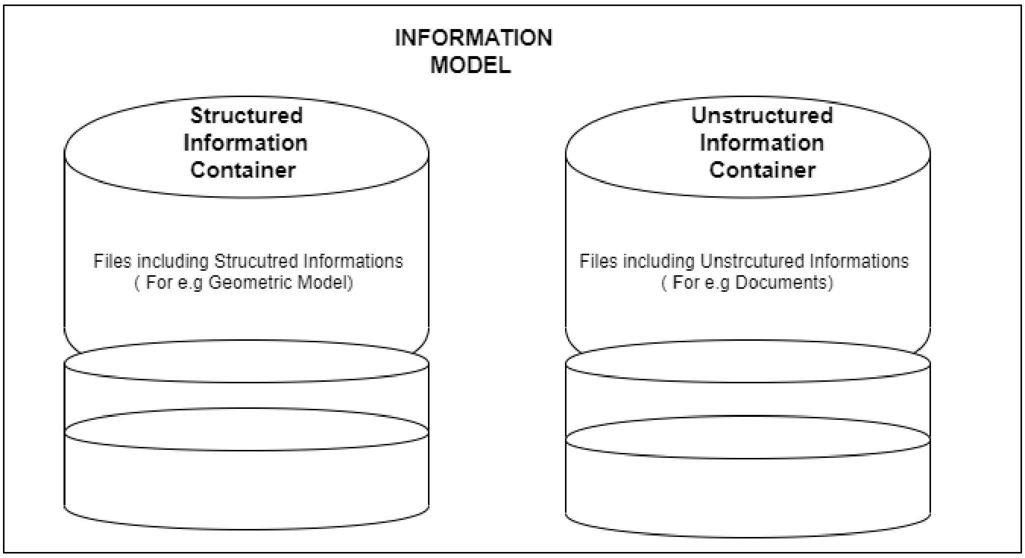



**Figure 9 - Concept of Information Model (ISO 19650, 2018)**

**Management of Information Container**

Key elements for the management of the defined information container are identified based on ISO 19650 series of standards (Ford & Try, 2020). These elements are

- States of the information container
- Management of Metadata assignment for the
    - The information container classification
    - Revision or the Version control

- Permitted use of Information

**States of the Information Container**

With the origination of information containers, it can exist in four defined states during its workflow within the process. The very similar principle was illustrated by PAS 1192, which defines four functional areas within CDE as 'Gates' which act as the sign off procedures as the information pass through the different sections. The figure below from ISO 19650 explains the different states of the information container (ISO 19650:1,2018):

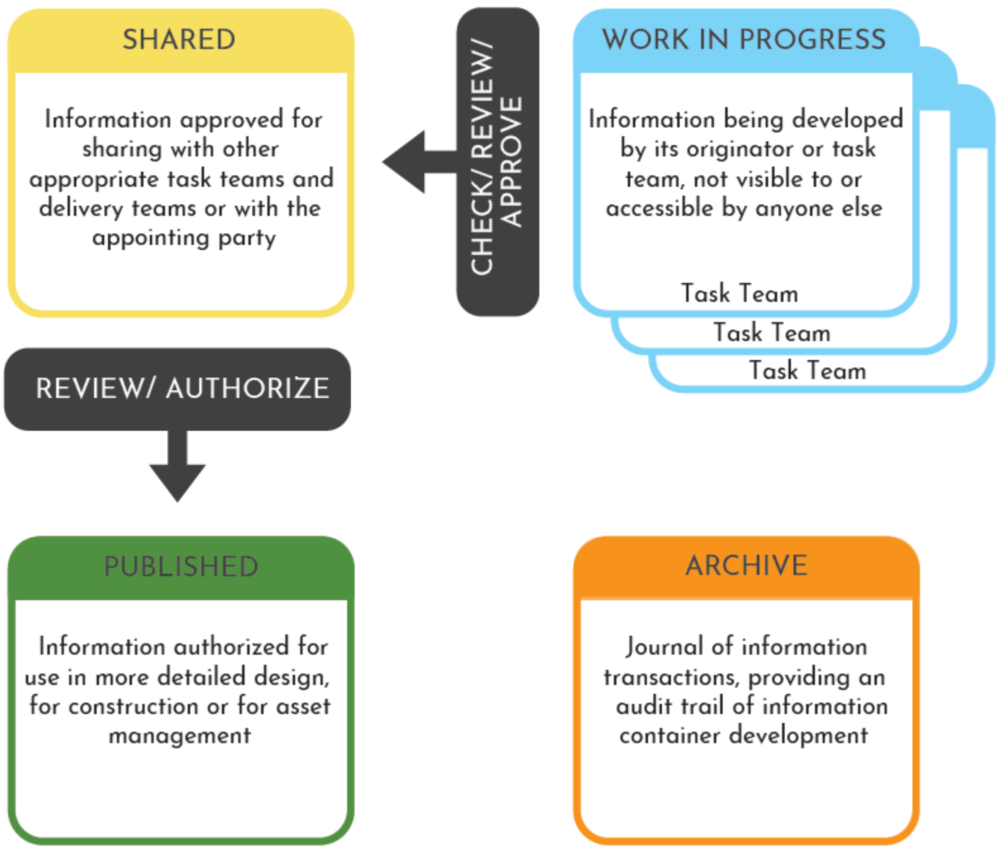



**Figure 10 - The concept of different states of Information Container (ISO 19650:1,2018)**

- **State of Work in Progress**: This state represents that the Information is being developed by the task delivery teams, and it is also for the knowledge of the client about the present status of the Information. It is passing off this stage required to sign off protocols to be followed by the internal task team. The Information at this stage is not available for the interdisciplinary coordination, and Information should not be accessed to other teams other than the task team assigned for the development of Information. Figure (4) about the representation of ecosystem hierarchy, the WIP state falls in the contractor's space. E.g., an appointed detail design contractor for the architectural design of the station building will work internally for the development of design, based on the contract requirements.
- **Shared State**: The "Shared" section of the CDE is used to store Information which has been approved for sharing with other organizations to use as reference material for their design

development. Here, the Information is used for the integration and collaboration within different multidisciplinary groups. E.g., Design information models from the Architect will be available to other civil, electrical, and other system contractors. The result of this state is fully coordinated Information. After Shared state, the Information passes through the review/authorize transition state.

- **Published State**: The "Published Documentation" section of the CDE shall be used to hold published Information such as coordination and validated design outputs for use by the entire project team, e.g., Good for Construction drawing issuance for the construction phase.
- **Archived State**: The archived state is used to hold a complete record of all superseded containers that have been shared and published during the information management process. A container in the archived state that was previously in the published state represents Information that might previously have been relied on for more detailed design work, for construction or asset management.

ISO 19650 (2), clause 5.17 (d), recommends that the adopted CDE should be able to support the transition between the states as mentioned above. Again, this illustrates that the definition of the actual processes based on the organizational workflows is an essential consideration before the technical solution's adoption.

**Management of Metadata assignment of the Information container**

The idea of segregating the complex information model into manageable pieces of Information in the form of information containers is fundamental in delivering consistent Information across the project and different task teams. The standards guide towards the unique ID for the information container with different fields, which are the crucial steps for the information federation and segregation. Additionally, metadata can be attached to the unique ID for further efficient management and organization of the information container. Systematic classification of Information helps in the ordering of the Information in a controlled and persistent manner.

- How to identify the Information Container within CDE?

ISO 19650 (2), National Annexure NA.2.2, guides that in UK the identification of Information Container within CDE to be presented as in the following Figure.

| Project | — | Originator | — | Volume/System | — | Level/ Location | — | Type | — | Role | — | Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

**Figure 11- File Naming Convention (ISO 19650:2, 2018)**

Also, it emphasizes structured information hierarchy for large-scale projects such as Cross-Rail based on location, contract codes, design disciplines, organization codes, document types, a master deliverable list which is standardized across all the contracts by the Employer, asset functions and its classification (Taylor, 2017). For the numbering of the information artifacts the following schema was used:

***<Contract>– <Originator>–<Discipline>–<Document type>–<Asset location/ Sub-location>– <Incremental number> (e.g. C330-SKC-O4-TPLCR076_ PT001-00001).***

A similar strategy has been explored in the case study of Maharashtra Metro Rail Corporation (see Chapter 5) in its approach of the Engineering Assurance File Naming Convention in the section 5.5 of this document.

- Revision and Status Control of Information Container

Clause NA 4.3 (Revision) of ISO 19650 (2), recommends for the revision or version control from the transition of the Information. It is imminent in the substantial projects to keep track of the revised version of the information artifacts. It is vital, in view of monitoring and establishes that the correct Information is getting shared with the correct stakeholders. The standard recommends the notation presented in the following Figure.

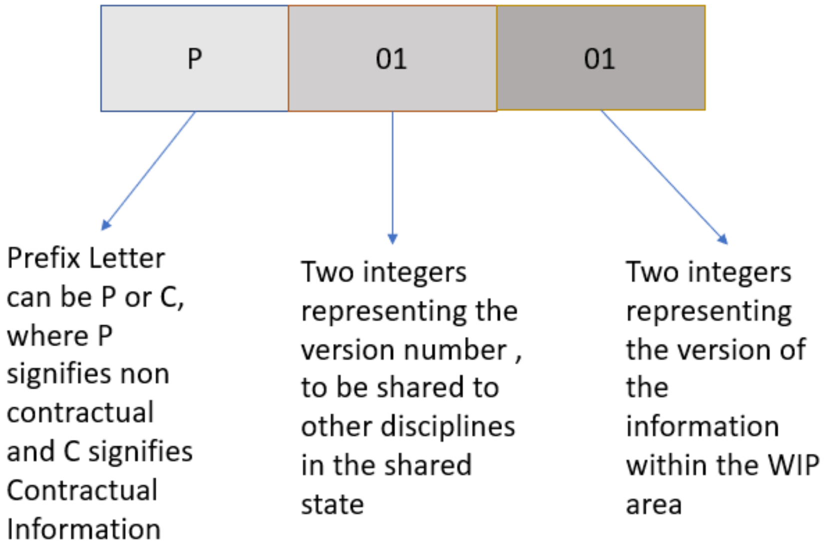



**Figure 12 - Revision Control Meta Data (ISO 19650:2,2018)**

Table number 3 NA.1, of ISO 19650 (2) represents the status code of the information containers. This is particularly important, to make it clear about the status for the use of the Information and informs about *where* the Information is presently within the workflow.

**Table 3 – Status Codes Table NA 1 (ISO 19650:2, 2018)**

| Code | Description | Revision |
|---|---|---|
| **Work in progress (WIP)** | | |
| S0 | Initial status | Preliminary revision and version |
| **Shared (non-contractual)** | | |
| S1 | Suitable for coordination | Preliminary revision |
| S2 | Suitable for information | Preliminary revision |
| S3 | Suitable for review and comment | Preliminary revision |
| S4 | Suitable for stage approval | Preliminary revision |
| S5 | Withdrawn* | N/A |
| S6 | Suitable for PIM authorization | Preliminary revision |
| S7 | Suitable for AIM authorization | Preliminary revision |
| **Published (contractual)** | | |
| A1, A*n*, etc. | Authorized and accepted | Contractual revision |
| B1, B*n*, *etc.* | Partial sign-off (with comments) | Preliminary revision |
| **Published (for AIM acceptance)** | | |
| CR | As constructed record document | Contractual revision |

The concept of State transition, Metadata regarding Revision and Status codes can be explained in the following figure.

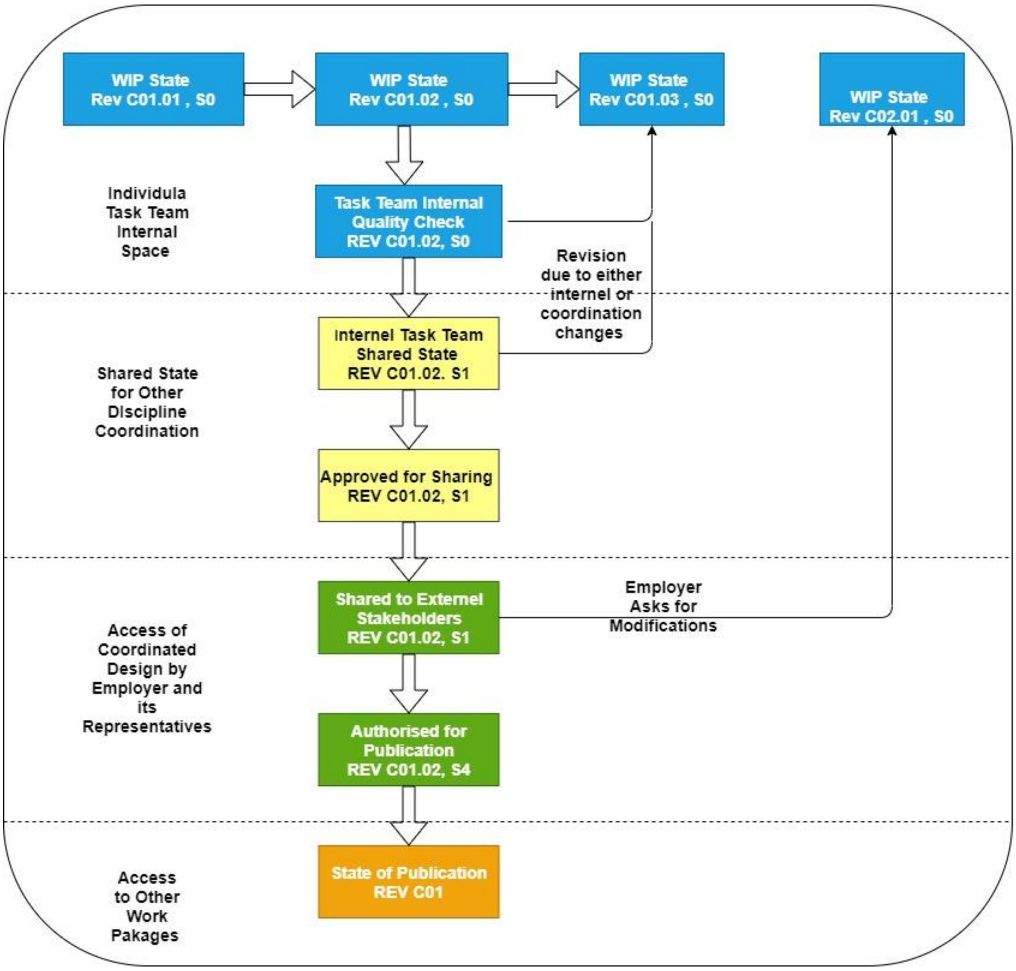



**Figure 13 - Workflow to explain the change of states, Revision and Status Control**

The figure described the transition of an information container which starts from the individual task teams with WIP status, then to the shared state for other discipline collaboration and, finally, to the external stakeholders as described in the sub section states of the information container above.

### 3.2.6. What are the Functionalities of the CDE?

This section explores the critical functionalities of the CDE recommended by the UK Government BIM working group – CDE subgroup, 2018. The fundamental purpose of CDE is to progressively support the information management and build-up of the required Information throughout the capital delivery phase of the project and information transition to the Operations & Maintenance of the built assets. The recommendations divide the CDE functionalities into five different areas:

i. Information Procurement within CDE: This functionality highlights the information procurement from the

   - Employer: to define the information requirements using Information delivery planning tool functionality of the CDE. This should enable the Employer to define and register the phase-specific information requirements at defined vital phases of the project. The Employer should also be able to use Master templates to define such requirements;
   - Supplier/Contractor: based on the requirements of the Employer, the contractor should be able to define information deliverables; this should include both the registering the deliverable lists and updating the planned program;
   - Information Exchange: The CDE platform to support the information exchange based on defined data structure protocols between different stakeholders. The platform enables the progress of the process of Information being supplied by the contractor as per the agreed time-bound deliverable list;
   - Information Integration with other systems: CDE should enable integration with other Enterprise systems like ERP solutions and Computerised Asset Management systems (CAMs) via APIs etc.

ii. Information Quality Assurance: To mitigate the risks of errors and inaccuracies, CDE platform should ensure autonomous quality assurances concerning the following

   - Assurance concerning the planned delivery schedule of the Information. This functionality also includes the possibility of recording any variations for the appropriate management information and actions;
   - Registered Files and data quality assurance: The CDE should validate all presented files and data according to the agreed structure protocols and standards;
   - Review and Authorization Workflows: CDE should be customizable in respect of defining the workflows suitable for the stakeholder arrangements of the project ecosystem;
   - CDE should generate detailed and user filtered Quality assurance reports based on the above quality factors.

iii. Storage and Security Features of the CDE: The storage feature for files and data should support both the native and open formats. The file or the information container states, as defined by ISO

/ PAS 1192, should be supported. The storage shall be fully configurable capable of registering, the transition between states, and archiving of the files. The types of documents shall be as per the project requirements, including commonly used open and conventional standards. The platform should be made secure from the potential threats of unauthorized access and data theft, by defining adequate log access control and secure IT infrastructure.

iv. User-level functionalities like File Management (naming conventions, metadata management, etc.), 3D Model Management features including easy navigation around federated models, Querying and searching features, Dashboards, and reporting, Audit trails, etc.

v. Information Output: The appropriately authorized and published Information of the CDE should be accessible to the platform's permitted and legitimate users. The export and download of the Information shall be as per the applicable procedures on the renaming and metadata assignments based on the blueprints of the processes.

### 3.2.7. Sample Workflow for the Railway Ecosystem

The sample workflow of the CDE for the review process of the Information for one of the possible ecosystem hierarchy, as shown in the figure 4, can be designed as shown below. This is just an example of the workflow, which can be customized based on specific requirements of the stakeholder interactions and respective project necessities.

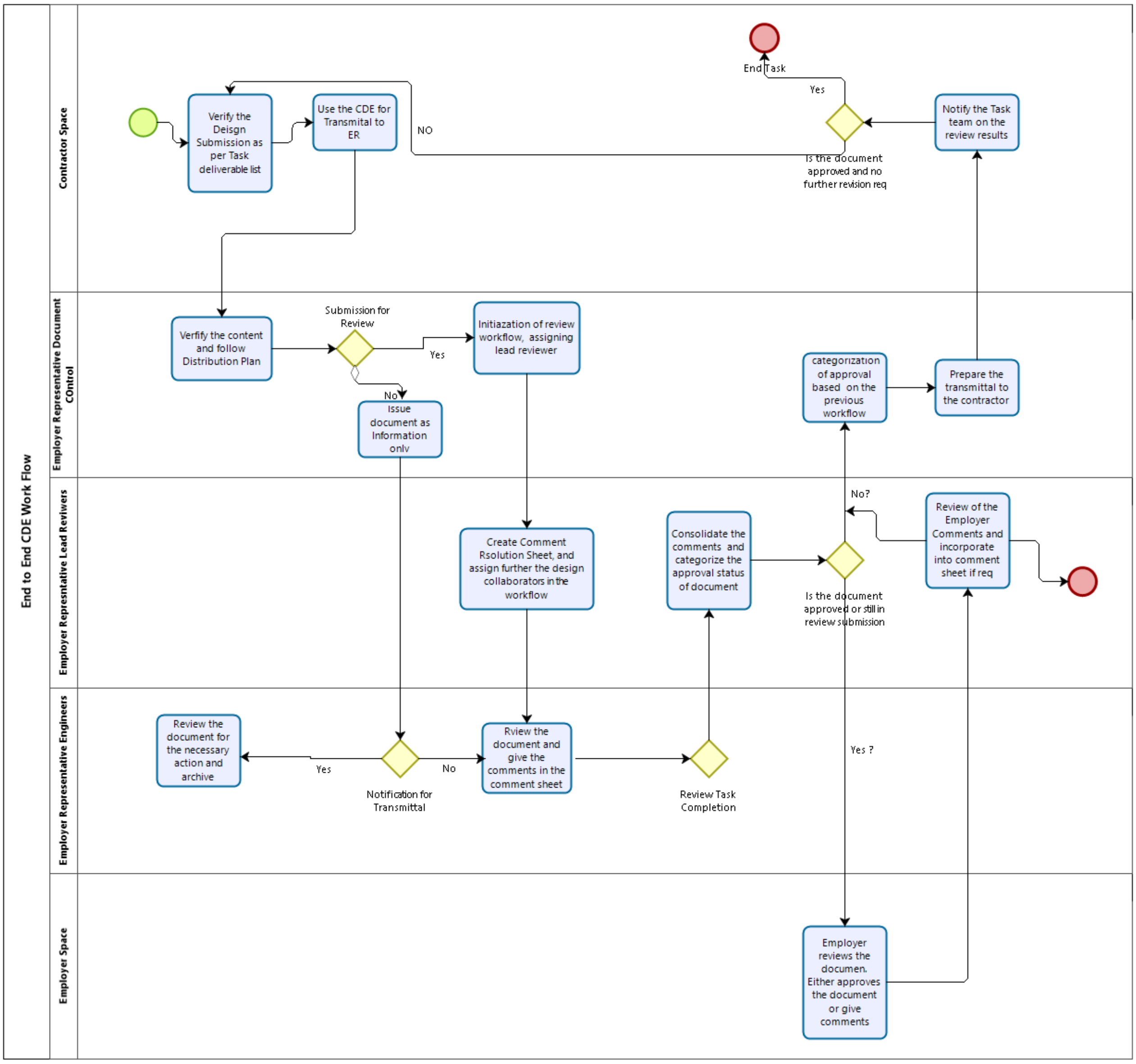



**Figure 14 - Sample End to End Workflow in CDE**

The sample workflow for the design review process as described above, divides the ecosystem into five different spaces as Contractor, Employer Representative Document section, Employer Representative's Lead Reviewers, Employer Representative's Engineers and the Employer section. The workflow can be further extended / modified in any of the sections. As an e.g. Employer's space can again be extended if more workflow for the review of the information is required. In the described workflow, significant importance is being assigned to the document control section, which can either fall with Employer representative or Employer's office. The end task for the complete review process, results as an integration gate to the other phase of the project. For illustration, issue of finalized Good for Construction drawing or 3D coordinated Model, which further will be developed into As Built Information Model during the construction phase of the project.

### 3.2.8. What should be the Implementation Approach for CDE?

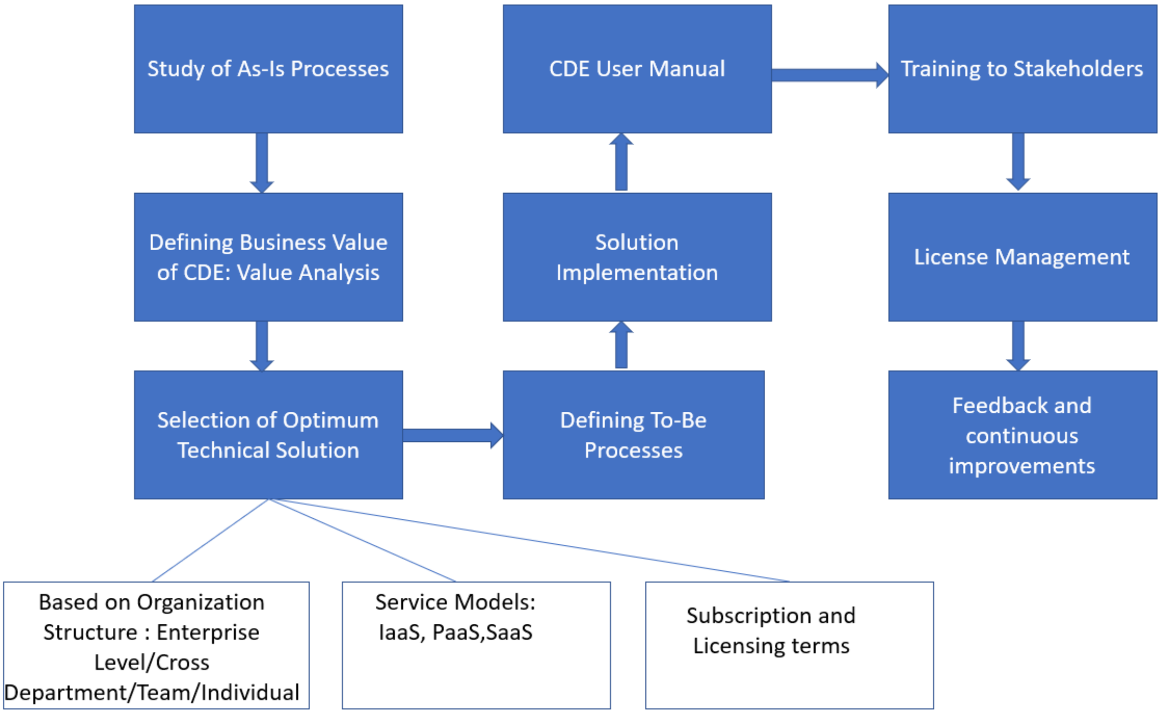



**Figure 15 - Implementation Approach for CDE**

The above literature reviews, and remarks represent the advantages of the adoption of CDE as an opportunity to adopt the BIM process workflows for the railway organizations. The concept of CDE inherently holds the benefits of integrating the complicated supply chain of the railway projects and also integrating the critical project phases for Information to be made sustainable through the project life cycle. The critical point emphasized by the various standards is the concept that process should define the technology for a CDE implementation and not vice versa.

# 4. INFORMATION REQUIREMENTS AND DELIVERY PLANNING

## 4.1. Information Requirements

This sub-chapter reviews and highlights the importance of Information Requirements as part of the Information Management process for a typical railway project. The recommendations of BIM information management standards and the guide books are considered to explore the concept of the elements of Information requirements and their interrelationships. The last part of the section outlines the contents and the relevance of Employer/Exchange Information Requirements (EIR) for identifying the client's information needs at different phases of the project. The essence of the thought, for starting the process with the end in mind and efficient transition of Information through different phases of the project, has been explored as the key to the Information requirements.

Information requirements are one of the most essential and fundamental aspects of the process of Information Management. Requirements Management is one of the well-researched areas that has been applied to many industries.

> *"Requirements management is the process of eliciting, documenting, organizing, and tracking requirements and communicating this information across the various stakeholders and the project team"* (Office of Government Commerce, UK Requirement Management).

Delivering right and the required Information, to the correct person, at the right time, is an essential consideration while exercising Information Management (Kometa & Olomolaiye, 1997). The factors influencing the decision to initiate a project process like strategical asset valuation or operations, further add further intricacies in defining the requirements for the capital delivery and asset management phases. The multidisciplinary, heterogeneous and fragmented nature of stakeholder and contract arrangements in the railway projects, makes it difficult for developing a consistent perspective regarding the Client's information requirements.

Client's requirements need to be developed systematically and appropriately disseminated to all the project actors throughout the whole project life cycle from the initiation phase to the Operations and Maintenance. Building Information Modelling (BIM) can be a means for project stakeholders to communicate, manage and deliver client's requirements (Hafeez et al, 2015).

The necessity to explore Information over the Whole Life Cycle (WLC) is also an important consideration (Dawood & Vukovic, 2015).

> "WLC information flow is defined as the steady and continuous evolution and use of BIM information and knowledge from the design stage, through the construction stage, to the facility management stage." (Dawood & Vukovic, 2015)

The pillars that enable Whole Life Cycle (WLC) information for a construction project, are technologies, standard processes, collaborative policies, and trained people. It would reduce inefficiencies associated with transiting Information from one project phase to another in a project (Dawood & Vukovic, 2015).

ISO 19650-1, on its clause 4.3, defines four perspectives of information requirements:

- Asset Owner perspective: To establish and maintain the purpose of the Assets created during the process. It represents the Government or Public body that owns the Railway project;
- Asset User perspective: To make sure that the delivered solution has the required quality. The department/company entrusted by the Government for the monitoring of the railway project on its behalf falls in this category;
- Project Delivery and Asset Management perspective: To plan and organize the work. This category can be represented by General Contractors, Detail Design Consultants or Maintenance companies;
- Society Perspective: To make sure that the community's interest is taken care during the asset life cycle.

**Elements of Information Requirements**

The elements for the Information requirements are like a jigsaw puzzle (Ashworth et all, 2019). It is crucial that each piece of the element have been understood and established considering their interdependencies. PAS 1192 and ISO 19650 series of standards define four elements, which are Organizational Information Requirements (OIR), Asset Information Requirements (AIR), Project Information Requirements (PIR) and Employer/Exchange Information Requirements (EIR). These elements form a part of the bigger Client Information Model (BIM Portal, Scottish Futures Trust, 2020).

On UK BIM framework guidance on ISO 19650 is defined the relationship between these elements in the following figure (Hooper & Bryan, 2020).

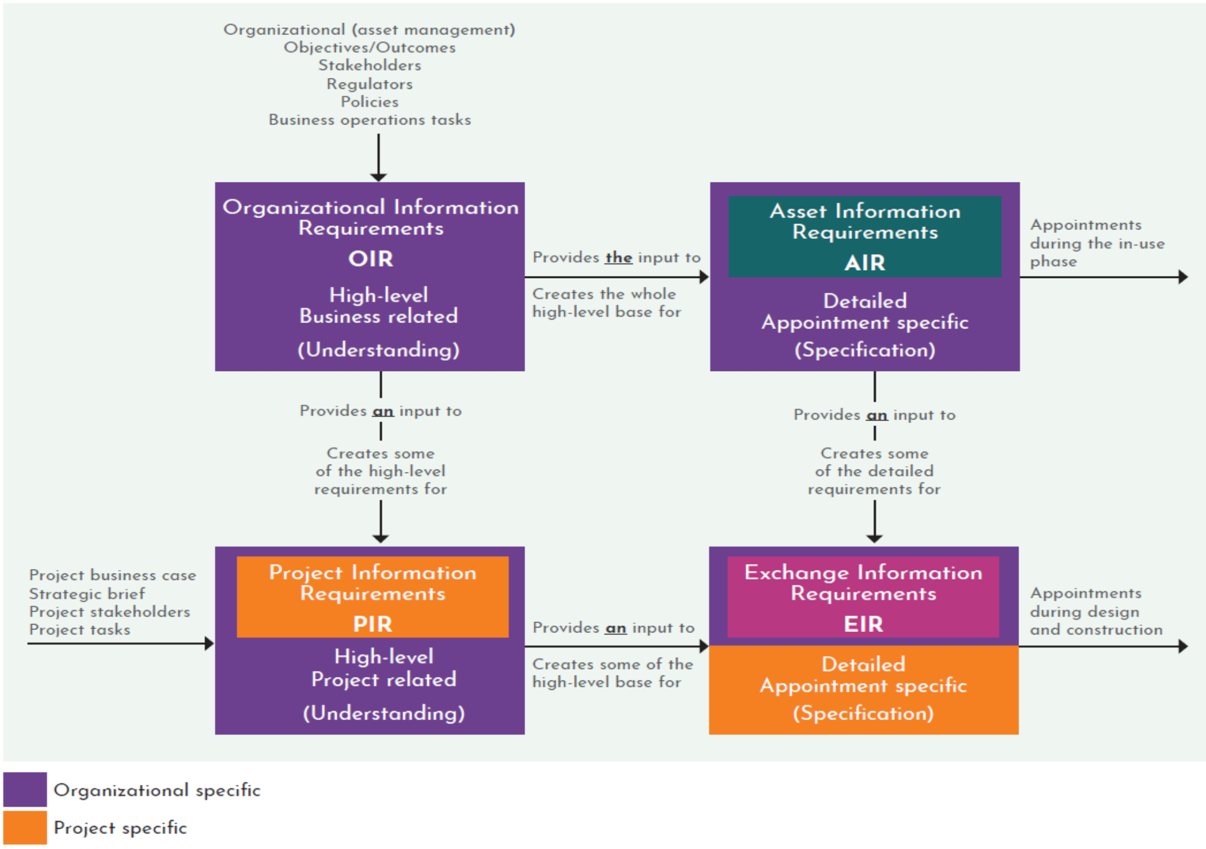



**Figure 16 - Hierarchy of Information Requirements (UK BIM Framework ISO 19650 Guidance, 2020)**

An explanation, relevance, and recommendations, for each of the above mentioned four elements, will follow, with a review based on PAS /ISO standards and framework guidance available.

### 4.1.1. Organizational information requirements (OIR)

The client information model starts by defining the high-level objectives of the organization. The Information and data captured at the initiation of the information management process to satisfy the organizational objectives are defined as Organizational information requirements (OIR). It encompasses the information requirements for the whole of the organizational Asset Portfolio and different departments. As an example, for railway project: Different System Engineering departments, Procurement, Train operational strategies, among others. Capturing the inputs and their feedback from different departments is crucial for correctly reflecting the strategical objectives for the produced Assets during the capital delivery phase.

ISO 19650-1 on its clause 5.2, mentions that the requirements of Information can be for many reasons such as, strategic business management, Asset management, regulatory purposes and policymaking functionaries.

Some of the high-level activities as extracted and adopted from PAS 1192-3:2014, Annex A.2 are as follows:

- Health and safety regulations and management;
- Environmental factors and Energy sustainability;
- Capital investment, lifecycle costing including Operations and Maintenance;
- Risk assessment and management;
- Maintenance and repairs philosophy;
- Operations strategies;
- Alignment Planning (in case of new Rail projects);
- Asset upgradations and renovations.

Emphasis has to be given to recognise the difference between the information requirements for a specific activity from the reasons for which the Information is required. As an example, Maintenance of Asset is an activity, and Strategy for Life Cycle Cost for Asset Portfolio, is the purpose of the Information.

### 4.1.2. Asset information requirements (AIR)

The gathering, aggregation, and structured manipulation of different elements of asset information are required to prepare the content required to answer an Organisation Information Requirement. The process of defining the OIR will generate a set of high-level requirements. These will need to be defined in sufficient detail to enable them to be used in asset management related contracts in the form of AIR.

ISO 19650 – 1 on its clause 5.3, mentions that AIR as to "set out managerial, commercial and technical aspects of producing asset information". The managerial and commercial aspects to cover the standards, protocols and procedures for the creation and the distribution of the asset information. While the technical aspect to cover the detailed metadata that will be required to support the OIR asset objectives. One example of this, is the specification of Reliability, Availability, Maintainability and Safety (RAMS ) parameter of the asset, to support the Maintenance management strategy. The standard also highlights the use of different AIRs for specific asset contracts by the lead appointing party/Employer. Also, lead appointed parties/contractors can further augment the information requirements for its other supply chain contracts.

As an example, AIR for a Railway project content could specify the precise Information needed for the Third Rail Traction System like:

- SIL Level (Safety Integrity Level);
- Service Life and performance parameters;
- RAM;
- Energy conservation;
- Preventive Maintenance Tasks;
- Durability;
- Failure Rate and Collective Maintenance Tasks;

This information needs to be tagged as the metadata with the model object while constituting the Asset Information Model.

### 4.1.3. Project information requirements (PIR)

Unlike AIR, which are detail-level requirements,

> *PIR explains the Information needed to answer or inform high-level strategic objectives within the appointing party concerning a particular built asset for project management and asset management processes. The requirements should support key decision points during the project (ISO -19650 – 1, 2018)*

ISO 19650-2 in its clause 5.1.2, contains a list of critical points that must be considered when defining the PIR as follows:

- The scope of the project;
- Relevant Key Performance Indicators;
- The intended purpose of the Information;
- Project Plan;
- Intended Procurement routes;
- Identification of Key decision points by the appointing party.

ISO 19650-2 in its clause 5.1.2 recommends that the appointing party considers the project plan of work in establishing the PIR. It enables key decision points and associated activities such as information exchange to be anchored against a defined plan, for example, the RIBA plan of work.

Usually, there is only one set of PIR per project for an appointing party. Development of PIR should go hand in hand with the strategic project management activities being defined, rather than as a standalone activity (Hooper & Bryan, 2020)

### 4.1.4. Employer/Exchange information requirements (EIR)

ISO 19650-1 in its clause 5.5, defines EIR as the aggregation of information requirements that set out technical, commercial, and managerial aspects of producing project information. The managerial and commercial aspects cover the standards, methods, and procedures to be implemented by the delivery teams and the technical aspect to specify those particular pieces of information needed to answer PIR. The expression of these aspects should align with the incorporation into project-related appointments.

The PAS 1192-2:2013 defines the EIR as a "*pre-tender document setting out the information to be delivered, and the standards and processes to be adopted by the supplier as part of the project delivery process*." It also notes the "*EIR should be incorporated into tender documentation to enable suppliers to produce an initial BIM Execution Plan (BEP)"*

One of the fundamental jigsaw pieces in the information requirement relationship model to enable BIM Level 2 information modelling, is the provision of a clear EIR (Ashworth et al., 2019). The aim of establishing a clear requirement is vital to ensure that stakeholder's information needs are clearly defined at the initiation of the different project appointments. EIR enables an instrument for coordination, thus, allowing project stakeholders to communicate, manage and deliver the client's requirements. A successful BIM project requires a clear EIR that establishes the methods to be adopted by the suppliers throughout the project life cycle (Hafeez et al. 2016). Hence, the introduction of EIR is crucial to address the information requirements and deliverables, the Employer requires, to make effective strategic and operational decisions.

The EIR needs to be ingrained at each hierarchical level of the ecosystem's supply chain, to endow the understanding of the information exchange requirements from each participant (Miskimmin, 2013). Without a properly structured EIR, the project may be rifted with the comprehensive benefits of the BIM processes (Mills, 2015).

An inefficient, unorganized and unregulated information transition from different phases of the project leads to a loss in money and time so, an EIR should be carefully developed at the start, with the end in mind (Tune, 2016).

For each contract appointment, despite the procurement method, as described in ISO 19650- 2, the role of the EIR is to precisely specify and point out what Information is to be delivered at each information exchange. EIR must be identified regardless of how the Information is delivered, be it by a geometrical model or other conventional data formats. Since every appointment is made up of information exchanges, EIR will always be required to specify what Information is needed and how it has to be exchanged among project stakeholders (Hooper & Bryan, 2020).

**Different sections of an EIR**

The UK BIM Task Group has developed the concept of EIR as a holistic framework for the UK construction industry to deliver the UK construction client requirements in projects using BIM. It includes a set of requirements and guidelines in three macro areas: technical, management and commercial (Hafeez et al., 2015).

The table below sets out the typical EIR (as defined by the UK BIM Task Group template) under these three main areas.

**Table 4 - Characterization of EIR Sections (UK BIM Task Group, 2013)**

| Management | Technical | Commercial |
|---|---|---|
| **Standardization:**<br><br>•Formal standards<br><br>**Organization and planning:**<br><br>•Stakeholders roles and responsibilities<br><br>•Planning the work and data segregation | **Standardisation**:<br><br>•Standard ICT solutions<br><br>**Software platforms:**<br><br>•BIM authoring environments<br><br>•Common data environment | **Standardization:**<br><br>•Standard areas of BIM<br><br>**Strategy:**<br><br>•Client strategic purpose<br><br>**Scope of work:** |

| | | |
|---|---|---|
| **Coordination:**<br><br>•Coordination and clash detection process<br><br>•Model review meetings<br><br>Collaboration:<br><br>•Collaboration process<br><br>**Information management:**<br><br>•Data segregation<br><br>•Security<br><br>•System performance constraints<br><br>**Risk management:**<br><br>•Healty and safety management<br><br>•Construction design management<br><br>•Compliance plan | **Communication:**<br><br>•Shared coordinate system<br><br>•Data exchange format<br><br>•LOD specification | •BIM and Project deliverables<br><br>•Schedule<br><br>**Assessment criteria:**<br><br>•Required BIM specific competences |

The key points presented in the above table, about the content of a prospective EIR will be explored and discussed on the following sub-sections and are based on the recommendations of templates and guidance from British Institute of Facility Management (BIFM) (Ashworth & Tucker, 2017), BIM Task group 2013, and BIM portal, Scottish Future Trust.

**Management Requirements of EIR:**

**Formal Standards**: In order to establish a consistent approach to collaboration, all parties in the project, and including the contractor's supply chain, must adopt and carry out their work in line with the recognized industry guidelines and standards (ISO 19650 Series, PAS 1192, Asset Management standards like PAS 55 series, BIM Forum LOD, UNI 11337 -2017, etc.);

**Stakeholders Roles and Responsibilities**: This section should bring clarity on the roles, responsibilities, and authority through a mature RASI matrix. Clearly defined requirements for each role, particularly those involved in the Information management process should be set. Some of the profiles are Client technical advisors, Asset Information Manager, Task Team Manager, BIM Managers, Task Team Information Manager, Interface Manager and Lead Designers and other BIM specific roles.

This section should make the project team aware of the allocation of roles associated with the management of the model and project Information through the capital delivery and asset management cycle;

**Planning the work and data segregation**: The contractor should manage the planning of modelling work and data segregation in line with industry standards, guidelines, and best practices. It includes at the minimum; Model Management (to ensure that the files are of expectable size), Collaboration practices, Naming conventions, Use of project CDE, Modelling methodologies, Level of Development, BIM object libraries, Incorporation of Metadata, Volume, Zones and Area. The contractor should be asked to provide proposals for the definitions of zones and the management of adjacencies within the model. Besides, the contractor also has to define the project volume structure.

**Coordination and Clash Detection Process**: The contractor's BIM Execution Plan (BEP) should also clearly address how the integrity of the model and other data sources will be maintained including details of:

- Details of their clash avoidance, clash detection / reporting, and clash resolution processes;
- Clash interference and Management software;
- Request for Information and Technical Query workflows;
- Tolerance strategy;
- Frequency of Workshops for coordination.

**Use for Health and Safety**: Railway projects are among the major infrastructure projects, where the safety guidelines are given utmost importance for both the project delivery and the passenger's operational phase. In the guidance on writing EIR based on the PAS 1192-6: 2018, BIM for health and safety group, notes some essential requirements which clients should undertake, to get benefit from sharing the health and safety requirements in the project life cycle. The Employer and the designers need to rigorously think about the future H&S issues and brought as part of the EIR for compliance of the contractor. Decisions made during planning and design should address the future health and safety hazards, including that of operations and maintenance. As an example, stations 3 D Models can help in the planning of passenger flow in the station premises and help in the planning of emergency evacuation plans. Some of the issues which can be adequately dealt by the BIM process management, presented in the paper are capturing H&S Information of the Asset as metadata, visual pictures, and models to foresee the risks associated with the built environment, better visualization of temporary works, site safety with the construction sequencing, etc.

**Security of the Information Model**: The purpose of this section is to communicate client-specific security measures required to secure the data and the Information. The stakeholders of the supply chain are required to consider and adhere to the security standards of the Employer's sensitive data (E.g., PAS 1192-5 and it may also include national or local guidelines).

**Compliance Plan**: This should encompass the Quality Assurance/Quality control procedures for the supply chain, which must be followed in the delivery phase. The level of assurances shall be made explicitly clear and contractor to demonstrate the same in its response through BEP, with the proposed information validation workflows and software. It is also essential that the period of aftercare, which is the number of years the model should be managed, is clearly defined.

**System Performance and Constraints**: This section aims to communicate to bidders any constraints in the Employer's systems or specific IT requirements, which may need additional resources or nonstandard solutions. Any limitations on maximum file size or other constraints should be established along with other performance-related requirements.

**Technical Requirements of EIR:**

**Use of BIM Software Platforms**: This section is essential for the project team to which software will be used for the authoring of information Models; different discipline experts likely use different software. The contractor will be required to explain in its BEP response about the BIM software going to be used by the delivery team. Attention should be given on the use of Open BIM standards outputs. It also includes mentioning of the Employer’s CDE, Asset Management Solution or any other Enterprise Resource Planning tools. The software should be mentioned along with the version numbers to avoid interoperability issues later during the delivery.

**Data Exchange Formats**: The motive of the section is to define the formats used for the supplier information exchanges. The file formats and where appropriate versions should be mentioned to ensure that exchanges are in a data format that the Employer can use, especially as a transfer to the Asset Information Model. It may include Native File format (from the authoring tool), Latest IFC version, PDF latest version, CoBIE.

**Common Coordinate System**: This section should define universal coordinates with all the project stakeholders. It is vital for Linear Infrastructure projects like railways, where linear spatial coordination and GIS software integration are crucial. Also, the Assets are to be mapped with linear Geo locations.

**Level of Definition**: The purpose of this section defines the scope of work in terms of the geometrical model and non-graphical Information for different Assets, aligned with the strategical BIM use cases defined by the Employer. The Employer can choose publicly available standards like Digital Plan of Work, NBS tool kit (https://toolkit.thenbs.com/). An example of railways overhead electrification systems is shown in the Figure below.

| Uniclass Code | Title | Initiation | | Concept Design | | Preliminary Design | | Detail Design | | Construction | | Handover | | O&M | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LOD | LOI | LOD | LOI | LOD | LOI | LOD | LOI | LOD | LOI | LOD | LOI | LOD | LOI |
| s_70_30_60 | Catenary overhead line systems | | | | | 3 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 |
| Ss_70_30_35_35 | High-voltage distribution systems | | | | | 3 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 6 |

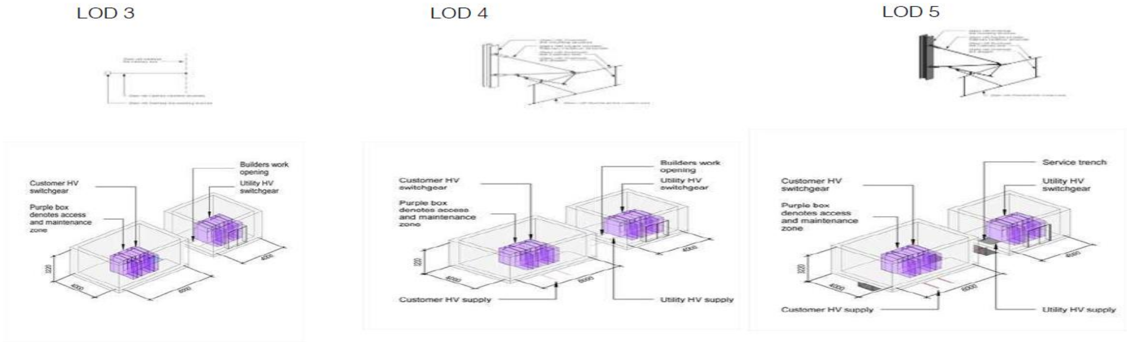



**Figure 17 - Sample LOD-LOI for railways overhead electrification system (NBS ToolKit, 2020)**

**Training**: This part should cover both pieces of training of suppliers for client-specific applications like CDE solutions and identification of training to be provided by the supplier.

**Commercial Requirements:**

**Exchange of Information/Data drops in line with defined project stages**: The information exchange should be based on the identified gateways and project control plans. It can be as per RIBA plan of work, which defines the project into seven key phases: Strategic planning, Preparation and briefing, Concept design, Spatial coordination, Technical Design, Manufacturing & Construction, Handover and in the Use phase. The contractor's Master Information Delivery Plan (MIDP) should demonstrate what Information is to be delivered and at what stage, aligning with the Employer's strategic planning of the project.

**Employers' Strategic Purpose and BIM deliverables**: This section is significant to define the scope of deliverables for the contractor. The employer should specify its objectives for BIM uses. The BIM use cases can be well defined based on the phase-specific recommendations from portals such as Penn State BIM uses and BIM excellence Model use list. A review of some of the BIM use cases in Railway projects will be explored on chapter 5.

**Suppliers Competency Assessment**: This section includes the Supplier competencies assessment into BIM Assessment, IT Assessment and Resource Assessments. The developed assessment forms should aim to capture the capability of the supply chain to deliver the project within a BIM working environment. The assessment includes supplier's BIM capability and experience, Evidence of BIM execution planning, Confirmation of BIM management software and tool kits, Details of information management workloads and resources allocated to the project and Principal Supply chain process.

### 4.2. Information Delivery

With the clear definitions of information requirements by the Employer, the planning of information delivery is vital which enable the tasks supported by it during the execution of the project (Dearlove, 2020). Outlining the delivery process, methods and standards are essential to consider the variables which can act along the project. ISO 19650 – 1, illustrates the generic specification and planning for information delivery in the figure below.

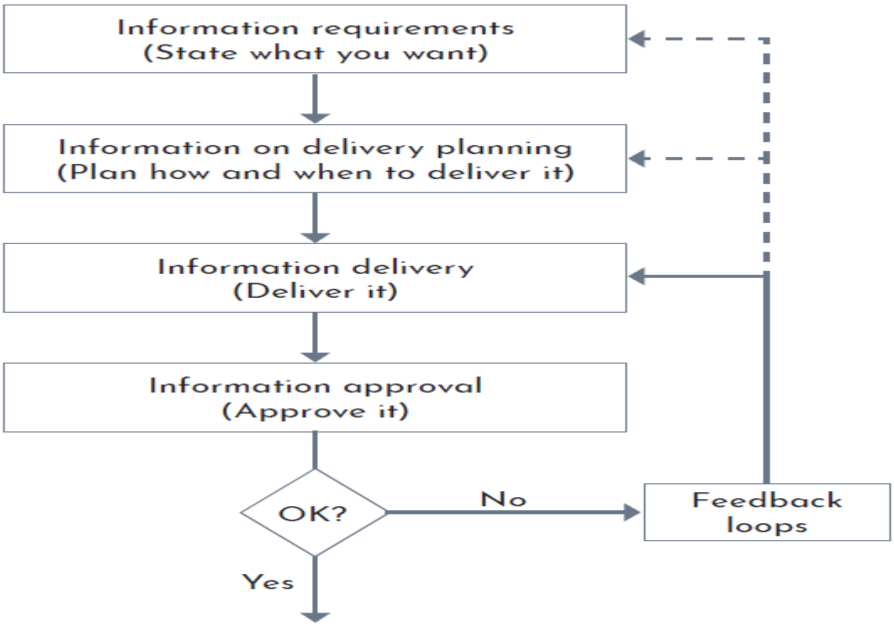



**Figure 18 - Generic Specification and planning of information delivery (ISO 19650-1, 2018)**

In the planning for information delivery, ISO 19650 – 2, clause 5.3.7 mentions the documents which has to be prepared by the lead appointed party on behalf of the whole of the supply chain as part of the tender response to fulfil the Employers information requirements. These documents are

- Pre-Appointment BIM execution plan;
- Capability and capacity assessment summary of the delivery team;
- Mobilization plan;
- Risk Assessment for the information delivery process;

#### 4.2.1. What is a BIM execution plan?

PAS 1192- 2 in its clause 3.6 defines BEP as the "plan prepared by the suppliers to explain how the information modelling aspects of a project will be carried out". With the advent of information management practices using BIM in the Mega infrastructure, BEP has emerged as a prominent document for the business and managerial aspects of managing BIM projects. It is an efficient document for defining flow of work and data inputs during the delivery of the information, for each phase of the project (Hadzaman et al, 2016). The important consideration of BEP is to synchronize and make fit the upstream information with the downstream use, to enable the effectiveness of the information delivery process (Christian, 2015).

PAS 1192- 2 in its clause 6.1.1 mentions that, as part of the procurement selection process, the employer shall request in the EIRs, that bidders shall submit details in the form of BIM Execution Plan for confirming of their strategy to project information management requirements, to demonstrate the supplier's proposed approach, capability, capacity and competence for the compliance of the Employers requirements. The BIM Execution Plan (BEP) is submitted firstly prior to the appointment to address the issues raised in the EIR (Pre contract BEP) and then, with more detail, post-contract award to explain the supplier's methodology for delivering the project using BIM (Post contract BEP).

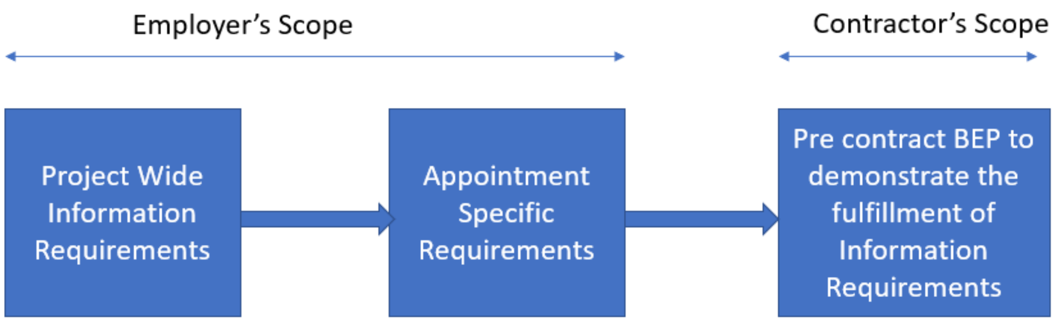



**Figure 19 - Information Requirements to delivery planning**

Dearlove (2020) states that BEP has explicit two different purposes in supporting the procurement, formal engagement and information delivery tasks for different phases of the execution and O&M:

- To provide **evidence** and affirmation to the Employer that the prospective supplier can manage and collaborate the project information management as per the information requirements provided to them in the form of EIR;
- To provide a list of **delivery tool** that the suppler and its supply chain's delivery team will use to initiate, exchange and maintain the project information during the appointment alongside other resources.

### 4.2.2. What is the structure of BEP?

ISO 19650-2 in its clause 5.3.2, recommends seven points which should be included as Pre contract BEP by the prospective interested supplier:

i. The details on the Names and the professional resumes of the individuals which will be undertaking the information management tasks within the supply chain of the delivery team. This will enable to consider the required resources at the early stage of the project and to ensure that functional competent professionals are engaged.

ii. The outlined information delivery strategy including:

   - How the delivery team will meet the information requirements of the Employer and its understanding of the Level of Detail requirements for different phases of the project. This will demonstrate to the Employer that the delivery team has understood the project requirements.

- Illustrating the objectives and goals for the collaborative delivery of the information by the supply chain of the supplier.
- The organization structure of the supply chain and their commercial establishment. This will ensure the Employer that project delivery team is well settled and established to deliver the project.
- The bifurcation of the delivery team into different task teams and their interrelations. Each task team may be responsible for its specific activity and also involve in the integration with other task team.

iii. The delivery team proposed federation strategy.

iv. The high-level responsibility matrix of the delivery team. Each element of the information model should be considered for assigning the responsibility and its deliverable. For example, Asset Management is the deliverable requirement of the element and the actor responsible for this will be Asset information Manager.

v. The delivery team's proposal for any modifications and amendments in the **production of information model** which in its perspective will improve the process of capturing the existing condition of Asset for an example in an refurbishment project, workflows for the authorization of the information, security protocols for the project and delivery of the information to the Employer. Supplier can consider Pre contract BEP as an opportunity to recommend which it considers as an improvement over the specified EIR.

vi. The delivery team's proposals for any modification and amendments in the **project information standards** for information exchange protocols between different task teams, exchange or distribution with external parties and with the Employer.

vii. The proposed schedules of software with versions, IT infrastructure which delivery team to adopt, to support the information management for the project. This is particularly important for the wider project information interoperability.

PAS 1192-2, recommends the relationship between documents for the information delivery process as presented in the following Figure.

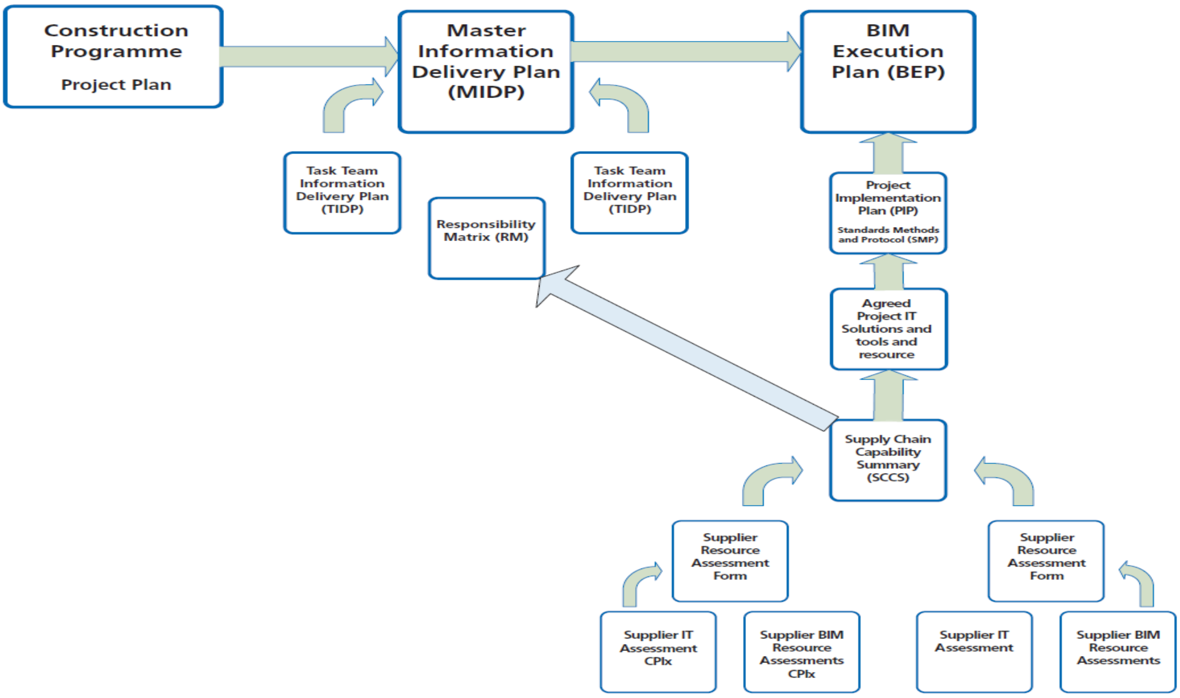



**Figure 20 - Relationship between documents for information management (PAS 1192-2, 2018)**

The above figure illustrates that BEP is composed mainly of two components which are Project Implementation plan and MIDP. Notice that in PAS 1192 -2, BEP is a single document with all the sources ingrained while as per ISO 19650-2, BEP is one of the documents submitted along with other resources (Dearlove, 2020). As mentioned in clause 5.3.7 (ISO 19650-2), documents like Delivery team capability and capacity, mobilization planning, risk assessment and information delivery planning are considered as the separate resources.

In summary the purpose of writing a BEP can be listed as follows:

- to assess the supplier team competency;
- how the supplier intends to make sure that Information Artifacts are submitted in accordance with the Scope, to the required schedule, LOD and quality;
- how the Supplier intends publishing Drawing information to support Design Reviews, costing, scheduling, transition to Asset Information model or any other identified purpose;
- how the Supplier intends working collaboratively with interfacing disciplines and contracts in order to eliminate coordination issues, design clashes and constructability issues;
- how the Supplier intends satisfying the Level of Definition (LOD) requirements;
- how the Supplier intends complying with the Employer Design, Review and Acceptance procedure;
- how the Supplier will help Employer achieve its BIM objectives in a manner which helps eliminate risk from the project and which promotes collaboration, innovation and right first-time design;
- how the supplier will establish and achieve the key performance indicators;
- how the supplier plan to establish delivery team risk register;

# 5. CASE STUDY ON THE IMPLEMENTATION OF BIM IN MAHARASHTRA METRO RAIL CORPORATION, INDIA

## 5.1. About the Project

Maharashtra Metro Rail Corporation Limited (MAHA-METRO), is a 50:50 jointly owned company of Government of India and Government of Maharashtra. The metro rail projects in India are covered under the legal framework of the Metro Railways (Construction of Works) Act, 1978; the Metro Railways (Operation and Maintenance) Act, 2002; and the Railways Act, 1989, as amended from time to time.

The existing Nagpur Metro Rail Corporation Limited (NMRCL) which is a joint Special Purpose Vehicle (SPV) of Government of India (GoI) and Government of Maharashtra (GoM), has been reconstituted into Maharashtra Metro Rail Corporation Limited (MAHA-METRO) for implementation of all metro projects in the State of Maharashtra outside Mumbai Metropolitan Region. The vision of the corporation is to create an energy efficient Metro Rail System of International standard which will enhance the quality of life of the citizens and be instrumental in the overall development of the city by making it more vibrant & attractive and utilize the full potential of 'Green Energy' in the form of Solar, Wind, etc.

Present portfolio of the corporation:

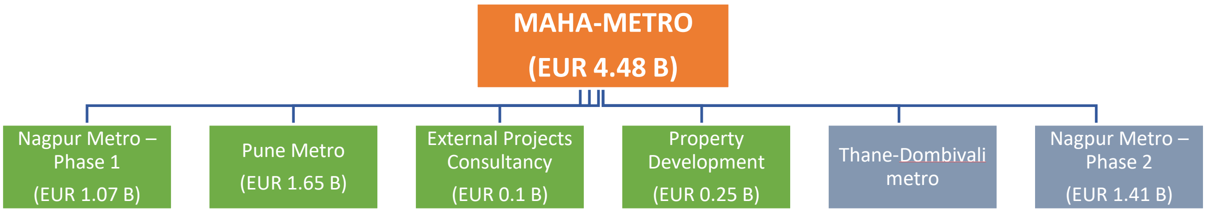
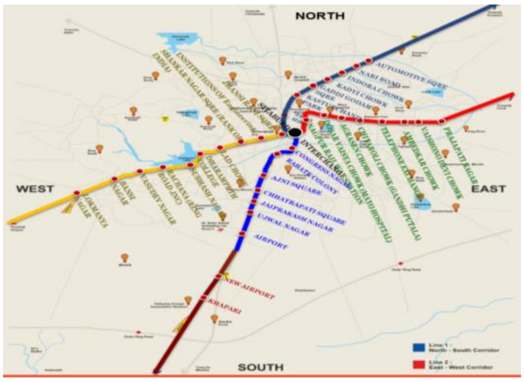



**Figure 21 - Portfolio of the Organization (Maha-Metro, 2020)**

Presently, Maha metro is undertaking the construction of two major Metro rail projects in the cities of Nagpur and Pune. The Nagpur Metro phase one consists of 38 stations and 2 Depots with total length of 38,215 kms, while the Pune Metro phase one consists of 30 stations with total length of 31,254 kms including 5 kms of underground section.

*The project involves the management of 40+ major contractors, 106+ major contract packages, 60+ DDC and 3D Modelling agencies working collaboratively, 100+ construction schedules and 1000 + users on the common data environment. The data represents complex, huge and multidisciplinary ecosystem ( Maha-Metro, 2020).*





(Map of Nagpur Metro) ( Map of Pune Metro)

**Figure 22 - Maps of Nagpur and Pune Metros**

## 5.2. Organization BIM Objectives

Maha Metro intended to create a Digital platform for Project Management comprising an ERP system and a 5D Building Information Modelling system along with other components. This will be the central repository of all information used by MAHA METRO. It will require information on project timelines, progress reports, estimates of material and costs, 2D and 3D drawings, to be submitted to the central system by contractors executing engineering, construction and other activities on site. The central system will also provide information to the contractors for execution.

All effort is to be made to create interfacing mechanisms using standards-based approach such that it can take and provide inputs to all kinds of systems built using industry recognized standards.

The ERP to have published standard APIs for integration and similarly the project management solutions can interchangeably read formats from the abovementioned popular tools. The standards used for drawing interchange include the popular DXF (Drawing Exchange Format) and ANSI standard IGES (Initial Graphics Exchange Specification).

**The Employer's Objectives**

- To achieve a world-class quality of service, achieve efficiency and practice better control over the financial transactions and project activities;
- Establish uniform standards for excellence in operations, project management, human resource management, financial management and performance reporting;
- To drive efficiencies in the production, modification, operation and decommissioning of its engineered assets through data driven information, improving decision making and delivering best value to its stakeholders;
- To institutionalise the use of the 5D BIM processes and solutions with the expectation that the solutions to become the backbone of the project during the design and build phase and subsequently for operations upon go-live of the project; with no change in the platforms envisaged unless the technology solution is declared obsolete and out of support;
- To make sure that project execution stays within the defined timelines and budgets with the best of quality resulting from world-class practices on scheduling, estimation and engineering;

- To institute good practise, collaborative techniques and behaviours which results in on-time and within budget project execution as follows:
    - A focus on design beyond 2D drafting and 3D modelling;
    - Early visualisation and comprehension by Maha Metro – enabling faster approval cycles;
    - Ease of coordination between construction documents;
    - Spatial Coordination between disciplines;
    - Clash detection and conflict resolution limiting issues on-site and during construction;
    - Extraction of intelligent data and automated schedules;
    - Ability to take-off materials and quantities;
    - Ability to link Models, Projects Schedules and Construction Sequencing;
    - Projecting future construction sequence conflicts;
    - Tracking and identifying location of material and pieces on-site in a simulated environment;
    - Transparent and realistic picture of the actual activities in the Project;
    - Visualisation of construction-sites for contractors, sub-contractors and clients onsite;
    - Integration of BIM with mobile-devices for managing construction and commissioning / hand-over;
    - View the current cost and compare it to the estimated total target cost of projects as well as interim costs against design during design phases;
    - Effective strategic and operational setup right from the beginning of the Project;
    - Implementation of an effective Operational Excellence in Initialisation & Execution;
    - True and fair view on financials, reliable forecast and what-if-scenarios;
    - Cost and Time optimised Program Management with early warning system in place for on-time management action;

- To procure/produce, manage and maintain data and information about the Maha Metro engineered assets that is complete, consistent and can be trusted and re-used for operational purposes and for future business intelligence.

## 5.3. Role of System Integrator in the Integrated delivery of the solution and Concept of Owner Support Office (OSO)

Maha Metro has conceptualized the project to deploy a proven integrated ERP (Enterprise Resource Planning) and 5D-BIM solution to automate its operations and integrate its processes. An Owners Support Office (OSO) was created which would depend on the mentioned solutions for strategic and operational design, delivery, execution and subsequent support.

*The key outcome of creating an OSO was, ERP & 5D-BIM implementation is linked to service delivery, operational excellence, transparency and compliance.* The role as OSO was vital to establish standards, guidelines and work as a centre of excellence for the whole ecosystem and the supply chain of the project.

Highbar Technocrat Limited along with the professional service companies was entrusted the task of delivering the integrated 5D BIM - ERP solution and setting up of OSO.

Key tasks entrusted to the System Integrator and OSO can be summarised as follows:

- Service delivery to internal and external stakeholders; monitoring KPIs, upload of directives and project execution;
- Operational Excellence in terms of integration of project and organizational functions, optimization of resource utilization, transparency and compliance of legal, financial & administrative legislations and frameworks;
- Standardization of processes, records, terminology, information exchange mechanisms;
- Establishment of digital platform to address the evolving needs and Phased implementation.

### 5.4. Organization Structure

The organization hierarchy consists of Employer at the top which has appointed Employer Representative (General Consultants), a group of professional consulting companies which works on behalf of the Employer to execute the project execution and the deliverables from the contractor.

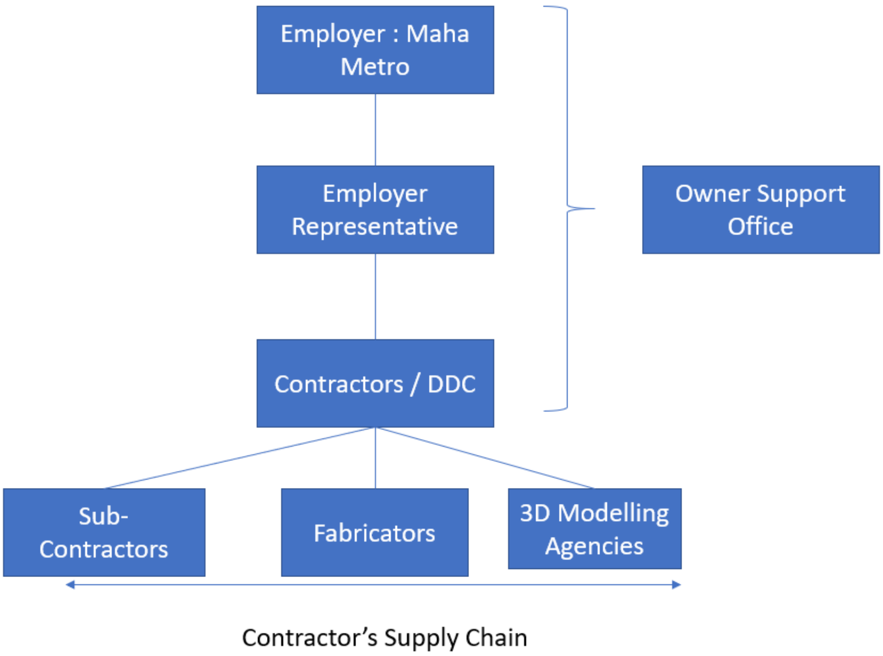



**Figure 23 - Maha – Metro Organization Hierarchy**

The organization structure encompasses the roles associated with the discipline specific roles including Project Manager, Lead technical reviewers and respective subject experts. Along with the Information management functions like Information Managers (with roles like BIM Manager, Asset Information Managers), and document controllers, the Employer, as part of its management of Information requirements, also listed the required information management profiles from the contractor.

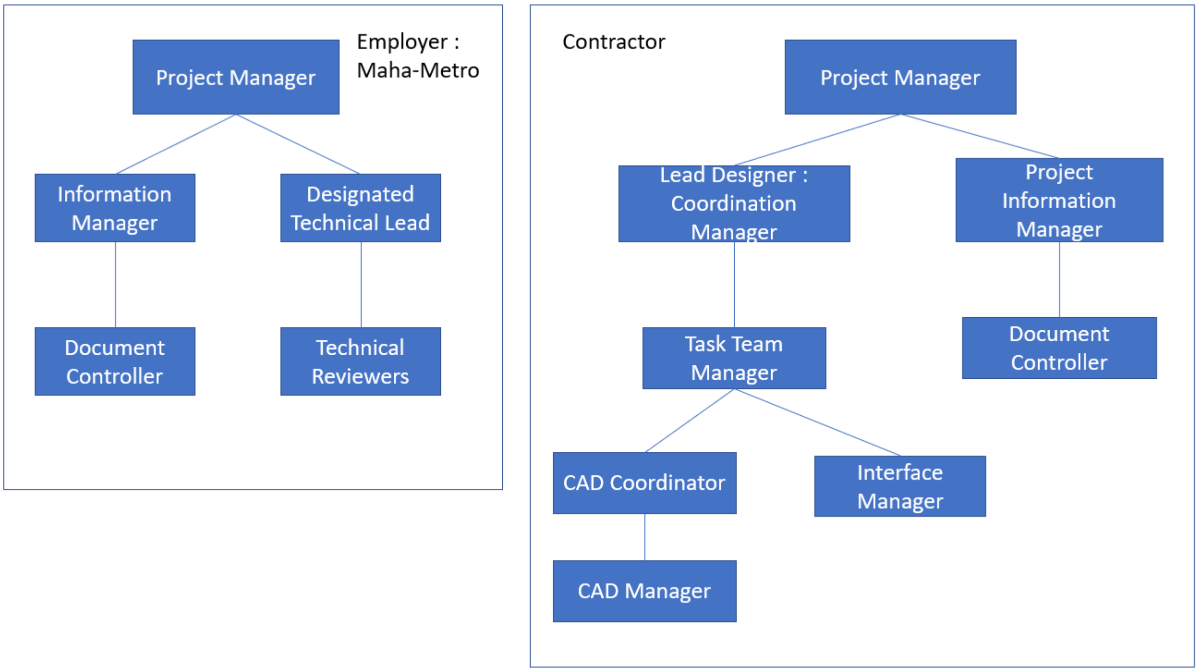



**Figure 24 - Maha-Metro Organization set up – including information management functions**

The figure below shows the Ecosystem workflow:

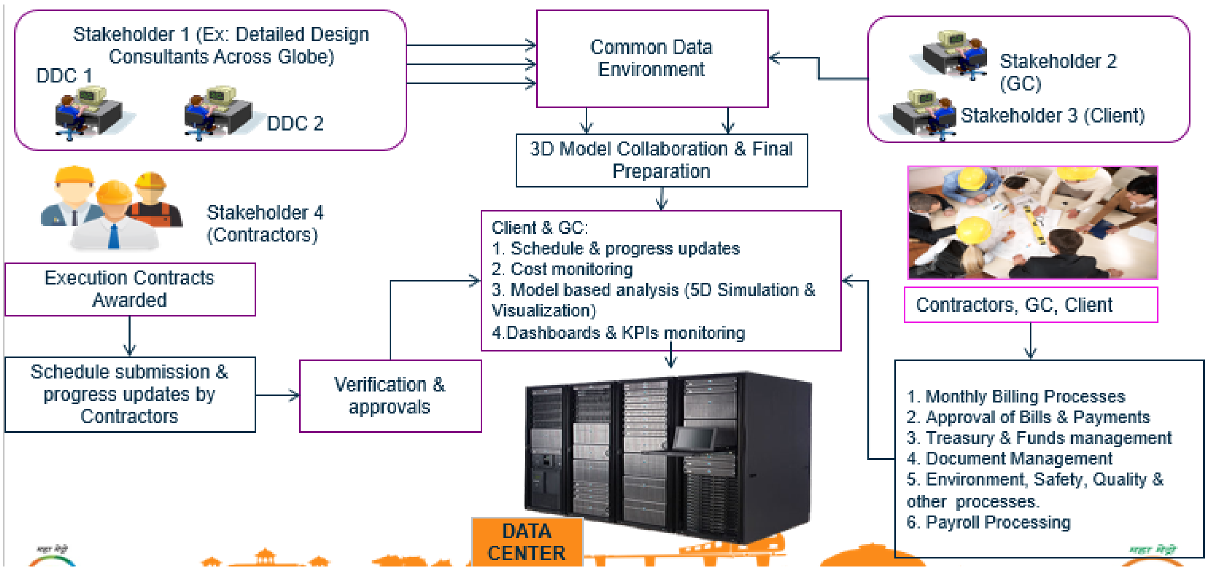



**Figure 25 - Ecosystem Workflow (Maha-Metro, 2017)**

## 5.5. Information Requirement and Delivery Planning

Understanding the importance of defining the information requirements of the organization, the first step of the process was the preparation of project wide information requirements along with the team of experts and the management. It was then adopted for the different appointment specific EIR's.

The purpose of the Employer Information Requirements (EIR) document was to provide specific details and instructions relating to Production Information and Handover Information [**Information Artifacts**] about the engineering solution of the Maharashtra Metro Rail Corporation's asset and how these shall be captured, authored, managed and submitted to the Maha-Metro or its agent [**the Employer**] by the Supplier / Detailed Design Consultant / Contractor [**the Supplier**].

The EIR sets out Employer's EIR standards, methods and procedures to be used for producing and managing Information Artifacts during each project phase, to make sure that the developed engineering solution meets project objectives and desired outcomes and benefits.

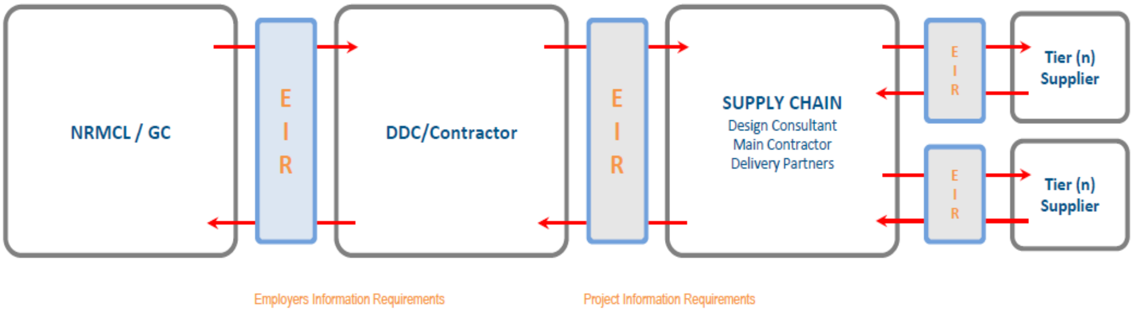



**Figure 26 - Verification of Common Business Issues and Opportunities (Maha-Metro, 2017)**

The figure below shows the process adopted for ensuring that the information requirements of the Employer are well understood by the information supplier.

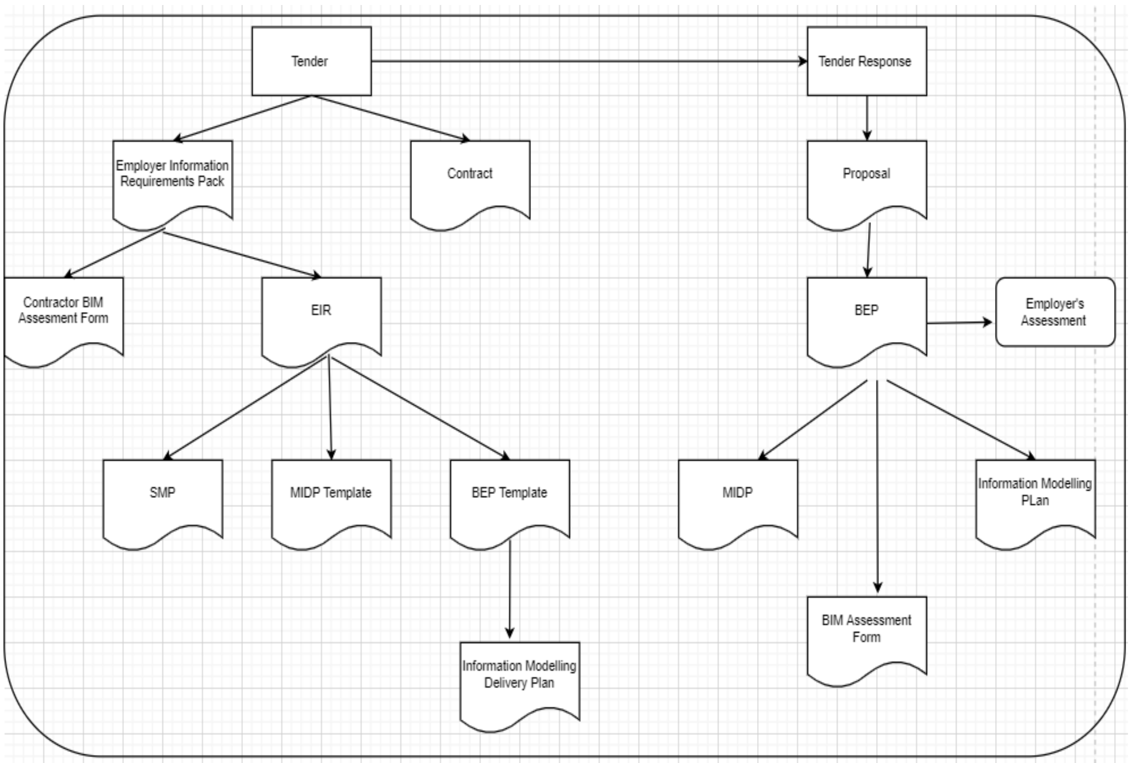



**Figure 27 - Adopted relationship between different elements of Information Requirements and Delivery Planning (Maha-Metro, 2017)**

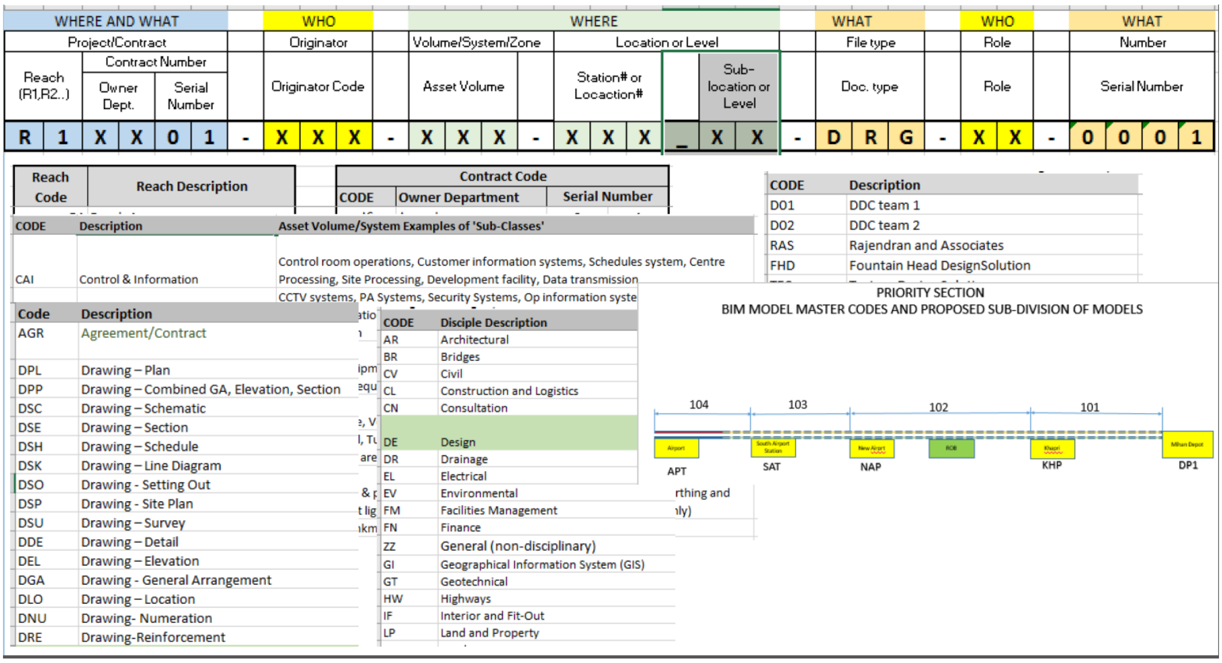
### Plain level questions

A set of plain language questions that the Employer intend to answer at each stage of a construction project. Key decisions such as whether to proceed to the next work stage or not will be made based upon the answers to these questions

### File Naming Convention

A organization wide common file naming convention was planned as part of the EIR, so that the Supplier make sure that a single File Naming convention is used for all Information Artifacts and that File Names are unique across the Project.

**Table 5- File Naming Convention (Maha-Metro, 2016)**




To meet the Employers BIM objectives a set of graphical and non-graphical information requirements for the objects and assets were sketched. The process was based on the collaborative workshops between discipline specific experts, BIM Managers and Asset information team.

| NMRCL Master Production and Delivery Table (MPDT) - Template | | | Gate 1 - Stage 01 | | Gate 2 - Stage 02 | | Gate 3 - Stage 03 | | Gate 4 - Stage 04 | | Gate 5 - Stage 05 | | Gate 6 - Stage 06 | | As Built Requirement | Stage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Uniclass 2015 Code | Title | Asset Volume | LOI | LOD | LOI | LOD | LOI | LOD | LOI | LOD | LOI | LOD | LOI | LOD | | LOI |
| Ss_20_05_50_65 | Precast concrete foundation and plinth system | | | | | | | | | | | | | | | |
| Ss_20_05_50_70 | Reinforced concrete base or foundation systems | | | | | | | | | | | | | | | |
| Ss_20_05_50_92 | Unreinforced concrete foundation with cast in products systems | | | | | | | | | | | | | | | |
| Ss_20_05_50_93 | Unreinforced concrete foundation and plinth systems | | | | | | | | | | | | | | | |
| Ss_20_05_65 | **Piling systems** | | | | | | | | | | | | | | | |
| Ss_20_05_65_24 | Driven precast or prestressed concrete piling system | | | | | | | | | | | | | | | |
| Ss_20_05_65_40 | In situ concrete augered piling system | | | | | | | | | | | | | | | |
| Ss_20_05_65_41 | In situ concrete bored piling system | | | | | | | | | | | | | | | |
| Ss_20_05_65_42 | In situ concrete cased displacement piling system | | | | | | | | | | | | | | | |
| Ss_20_05_65_43 | In situ concrete displacement piling system | | | | | | | | | | | | | | | |
| Ss_20_05_65_44 | In situ concrete mini-piling or micro-piling system | | | | | | | | | | | | | | | |
| Ss_20_05_65_64 | Plunge column piling systems | | | | | | | | | | | | | | | |
| Ss_20_05_65_76 | Screw piling systems | | | | | | | | | | | | | | | |
| Ss_20_05_65_84 | Steel bearing pile systems | | | | | | | | | | | | | | | |
| Ss_20_05_65_89 | Timber piling system | | | | | | | | | | | | | | | |
| Ss_20_05_90 | **Underpinning systems** | | | | | | | | | | | | | | | |
| Ss_20_05_90_10 | Beam and pier unreinforced concrete underpinning systems | | | | | | | | | | | | | | | |
| Ss_20_05_90_35 | Grouted underpinning systems | | | | | | | | | | | | | | | |
| Ss_20_05_90_45 | Jacked pile underpinning systems | | | | | | | | | | | | | | | |
| Ss_20_05_90_46 | Jet grouted underpinning system | | | | | | | | | | | | | | | |
| Ss_20_05_90_50 | Mass concrete underpinning systems | | | | | | | | | | | | | | | |
| Ss_20_05_90_60 | Pile and cantilever support underpinning systems | | | | | | | | | | | | | | | |
| Ss_20_05_90_61 | Pile and needle underpinning systems | | | | | | | | | | | | | | | |
| Ss_20_05_90_70 | Raking pile underpinning systems | | | | | | | | | | | | | | | |
| Ss_20_10 | Structural frame systems | | | | | | | | | | | | | | | |
| Ss_20_10_30 | Footbridge structure systems | | | | | | | | | | | | | | | |
| Ss_20_10_30_30 | Footbridge systems | | | | | | | | | | | | | | | |

**Figure 28 - Sample MPDT for defining Level of Development (Maha-Metro, 2016)**

## 5.6. Technical Solution

The following stack of software applications and functions:

i. Collaborative document control and management services (Bentley Project wise and Asset wise);

ii. Scheduling services (Oracle Primavera P6);

iii. Progress and performance with visualization on the Information Models (RiB i2);

iv. Enterprise wide SAP ERP implementation.

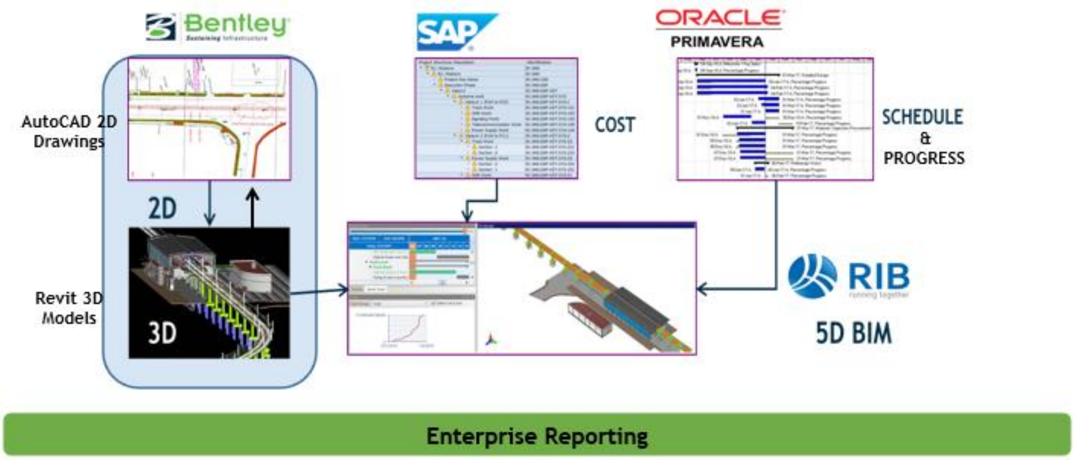



**Figure 29 - Technical Solution; Using four different software stacks (Maha-Metro, 2016)**

### 5.7. IT Infrastructure

A robust and efficient IT infrastructure is vital to support the wide array of digitalization solutions. The large number of process collaborators, which are geographically not co located requires the implementation of a fast, reliable and secure supporting IT hardware and data networks. Maha-Metro placed important emphasis on the hardware and data network requirements to maintain its enterprise digital platform right from the procurement stage.

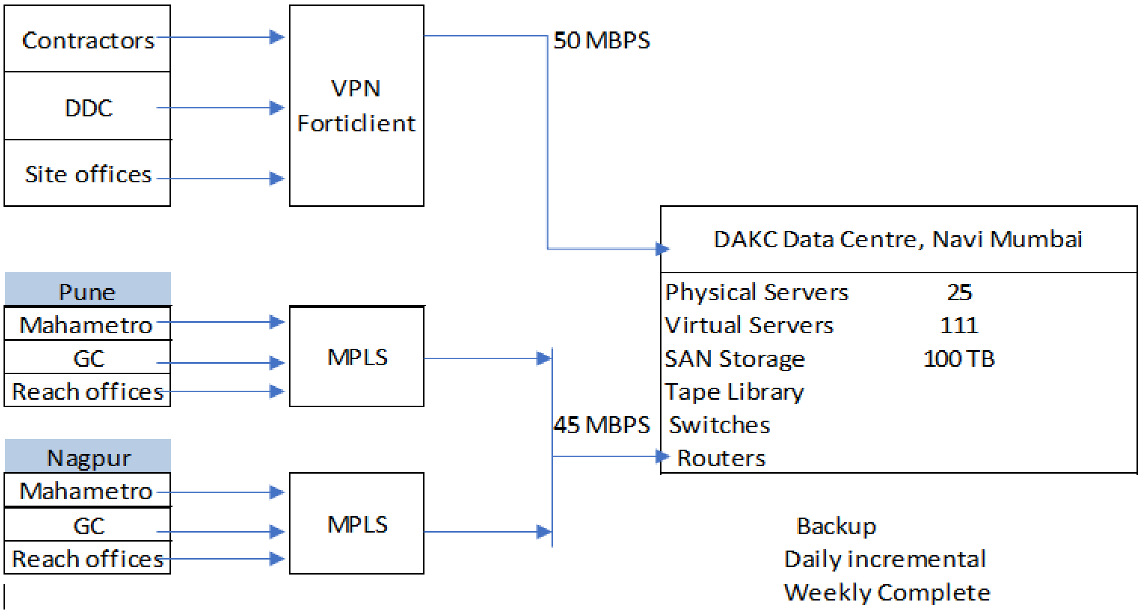



**Figure 30- IT landscape Diagram (Maha-Metro, 2016)**

### 5.8. Common Data Environment

Implementation of Common Data Environment (CDE) in support of best practices, standardized policies, procedures and processes for producing information for the full asset lifecycle across the design, planning and construction stages for reuse into operations and maintenance was critical to support Maha Metro’s BIM strategy.

The process starts with developing individual intelligent 3D models in an engineering modelling and design application catering to various disciplines such as track design, viaduct design, signalling, station buildings, geospatial analysis, geotechnical and miscellaneous civil works. All the discipline applications seamlessly collaborate with an Engineering Design Integration Collaboration System which shall form a central repository for all the design engineering information that is being created (3D models, 2D drawings, and analysis and design documents). The system supports readymade templates as per widely used BIM standards around the globe and store common data such as topographic and aerial maps, libraries, seed files etc. and other relevant documents.

Individual discipline 3D models are then be integrated to come up with a master model and converted into a model which will then be submitted for review and markup. The system also used for clash detection (especially for the subsurface utilities), schedule simulation and quantity take offs. It acts as a contextual tool for visualization, analysis and reporting of project information.

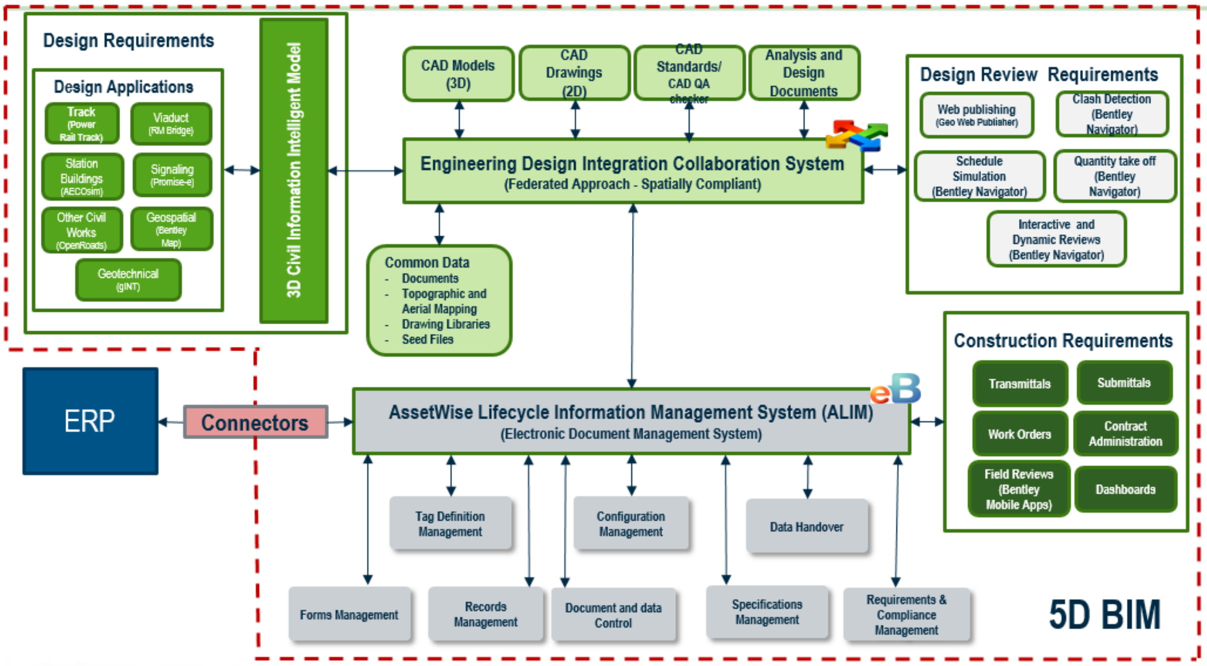



**Figure 31- High-Level Overview of Technical Solution: Interface of Engineering Design and Life Cycle Information Management Systems (Maha-Metro, 2016)**

Broadly, there are two main components of the established CDE

**ProjectWise Design Integration (PWDI)** – ProjectWise Design Integration allow multiple parties to work collaboratively on models and drawings across distributed offices, and control approval and visibility of these items via a BS1192 workflow process. Drawings passed from PWDI to AssetWise ALIM (eB) once they are ready for 'client' acceptance;

**Asset Wise CDE (eB)** - uniquely integrates configuration and change management best practices to deliver powerful asset lifecycle information management capabilities bringing structured (Assets) and unstructured data (Documents) together. AssetWise CDE (eB) is used as the Central Document Register and common platform for bringing all Project deliverables together, providing a holistic view for all Project users with the mechanism to identify and manage deliverables and work package submissions

A collaborative design authoring and review process was designed based on the principles of a common data environment takes advantage of 'Sharing' of common information with the focus on minimizing losses or misinterpretations and maximizing the re-use of data and increasing effective communication within teams and with external partners and agencies.

*As the BIM engineering data handover processes matures for both structured and unstructured information and the applicable Metro Project business processes are aligned between all parties, the AssetWise CDE (eB) provides a more comprehensive and relevant set of engineering information that accurately depicts the 'current' state of a particular design throughout its lifecycle to support BIM and Configuration Management best practices.*

Master Deliverable Lists (MDL) Structures are configured within CDE to assist the Design Contractors with a visual way to manage their work package deliverables. This also provide the Employer with high level visibility and a means to accurately report on the status of the contractor's deliverables.

The CDE security model is designed to support the access controls necessary for managing the progression of the design files and models through the BS1192 workflows and enabling the appropriate access privileges to the users based on their discipline's memberships.

Many customised dashboards and reports were configured in the CDE, to provide real time visual quantification for the control and performance management of the contract deliverables by Maha-Metro.

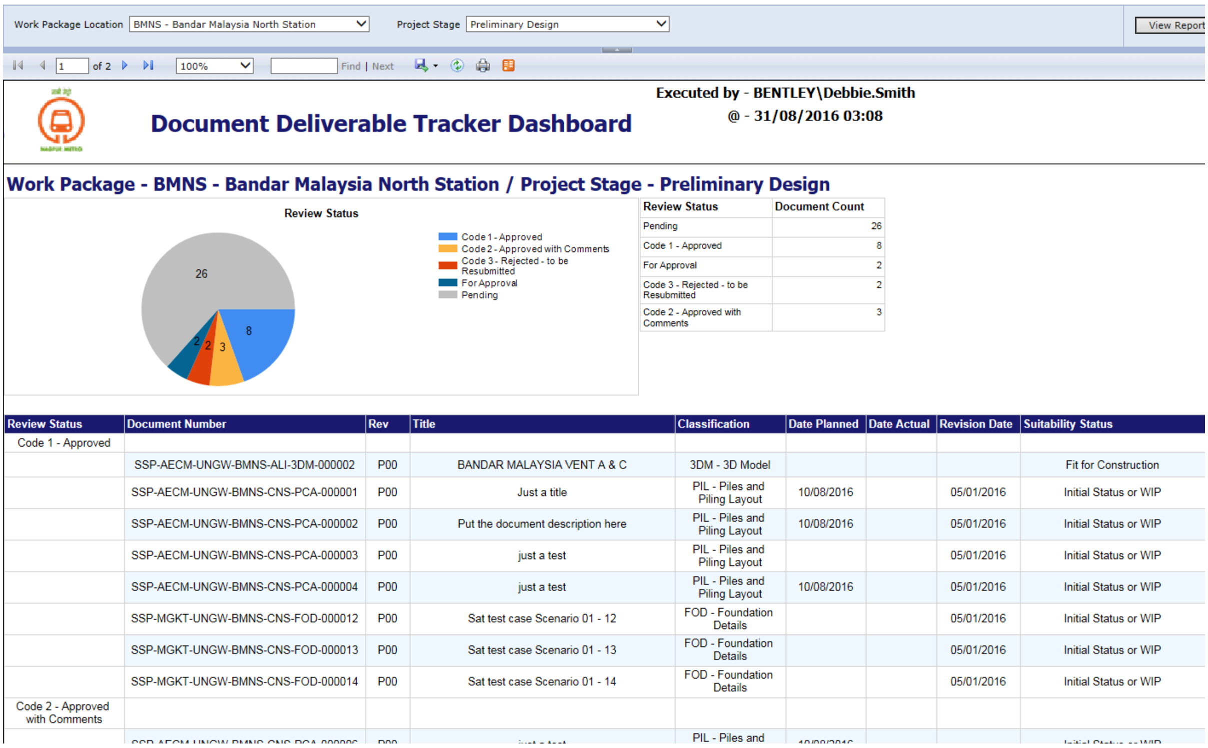



**Figure 32- Document Tracker Dashboard Sample (Maha-Metro, 2016)**

## 5.9. Some BIM Use Cases

The integrated digital platform provided integrated view of project by linking 3D model (Bentley), schedule (Primavera), cost (SAP). The Integrating time from Primavera & actual cost information from SAP to analyse physical progress and financial progress of the entire project. The cost estimates through the quantity takeoff helped in the more efficient procurement stage, and the monitoring of actual versus estimated quantities led to a more beneficial change control mechanism. The change or quantity variation control is vital for the success of the project within allotted time and cost, it seems as one of the inevitable benefits of using BIM processes and subsequent use of the information models.

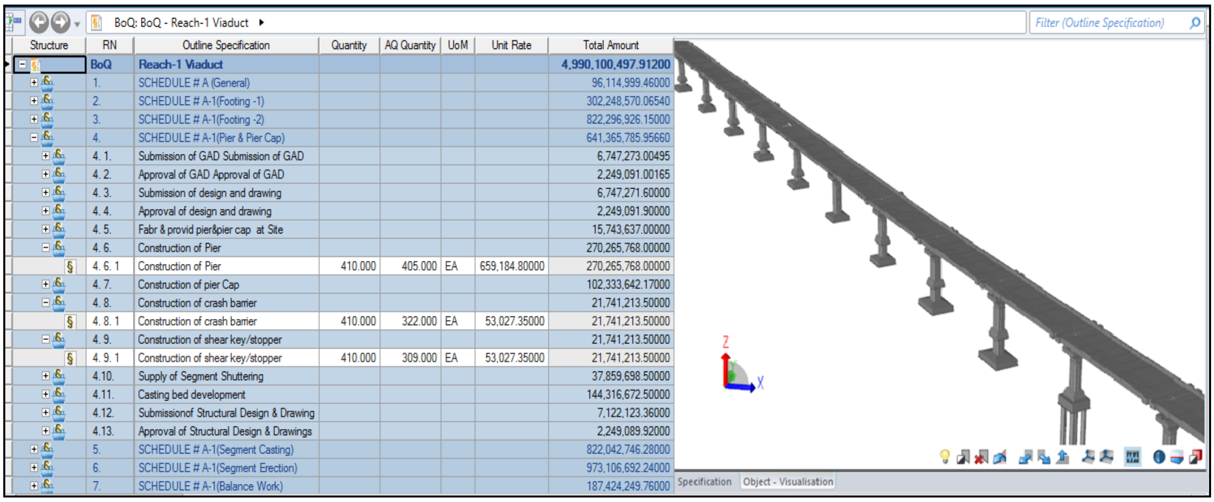



**Figure 33 - Quantity Change Management (Maha-Metro, 2017)**

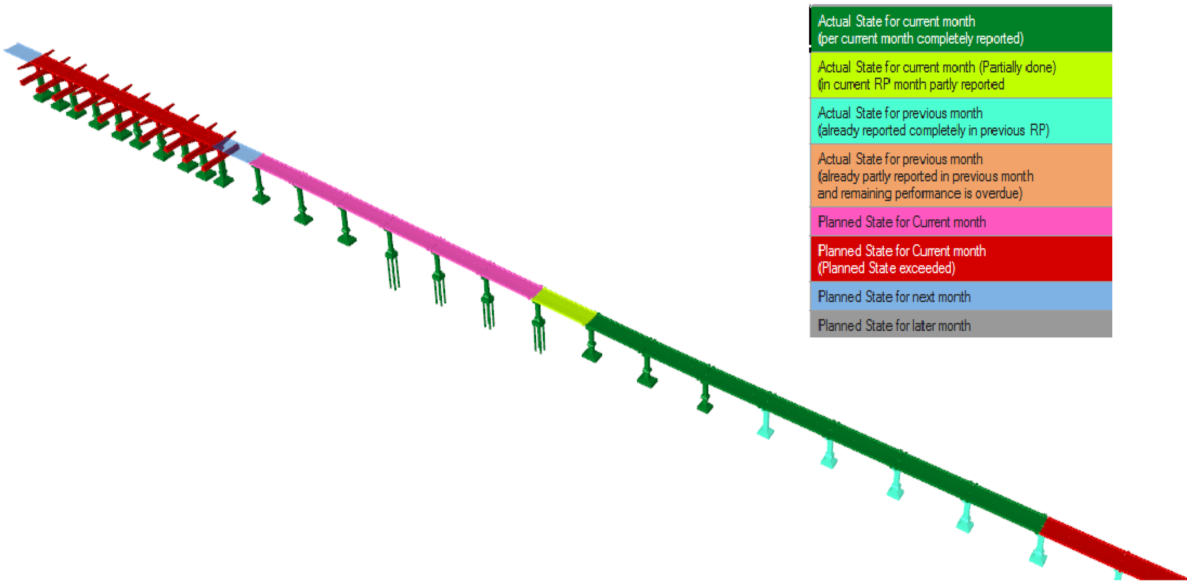



**Figure 34 - Delay Analysis and Visualization of Status of work by integrating the 3D Models and the project schedules (Maha-Metro, 2017)**

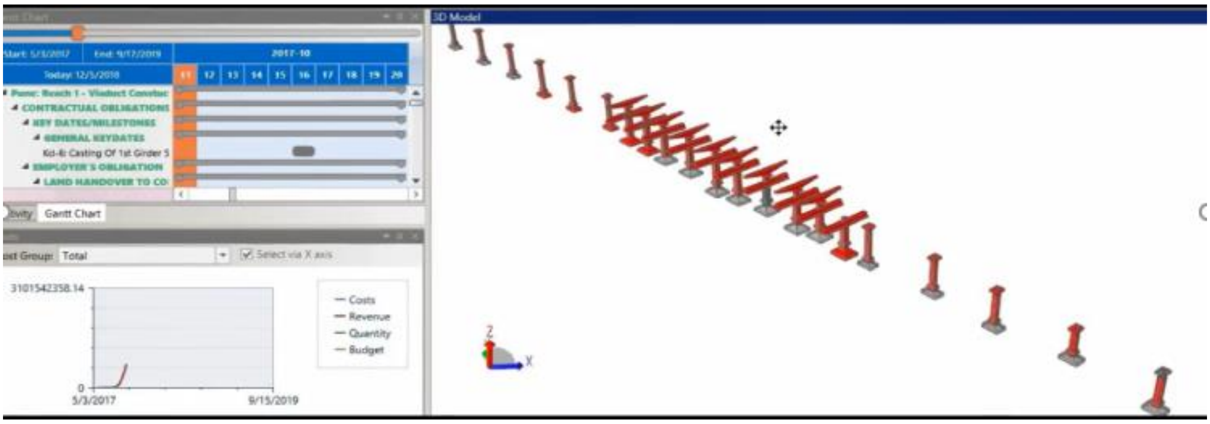



**Figure 35- Construction Simulation for better planning and controllability (Maha-Metro, 2017)**

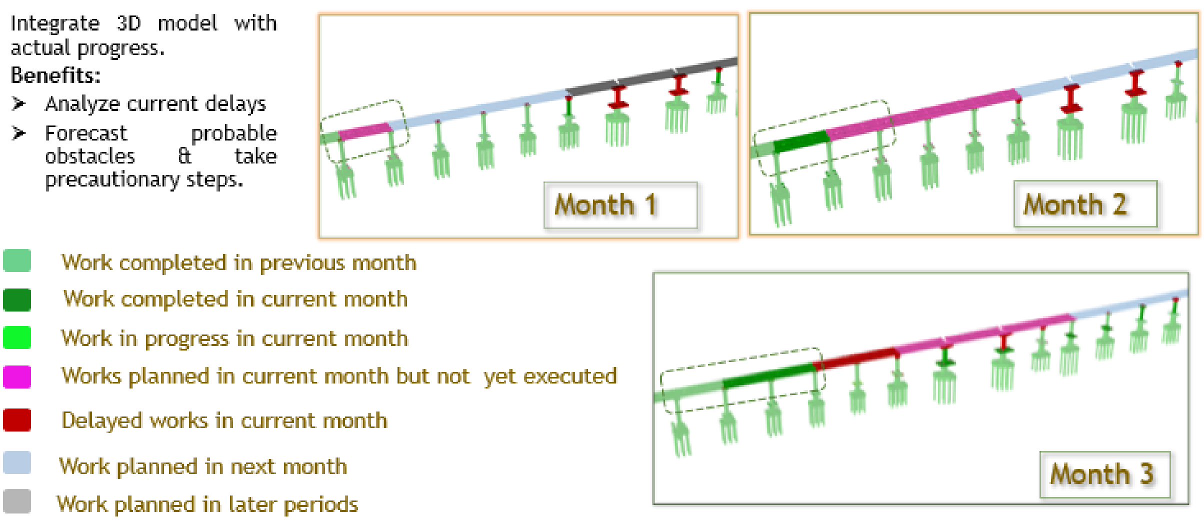
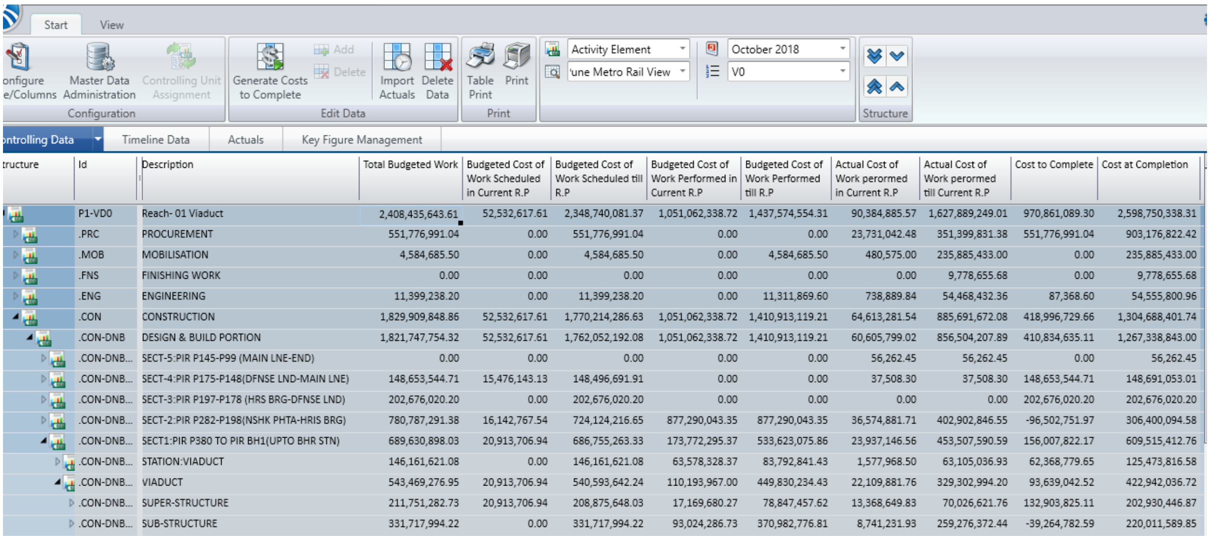



**Figure 36 - Use of 4D BIM for Project time Management (Maha-Metro, 2017)**



| Id | Description | Total Budgeted Work | Budgeted Cost of Work Scheduled in Current R.P | Budgeted Cost of Work Scheduled till R.P | Budgeted Cost of Work Performed in Current R.P | Budgeted Cost of Work Performed till R.P | Actual Cost of Work peromed in Current R.P | Actual Cost of Work peromed till Current R.P | Cost to Complete | Cost at Completion |
|---|---|---|---|---|---|---|---|---|---|---|
| P1-VD0 | Reach- 01 Viaduct | 2,408,435,643.61 | 52,532,617.61 | 2,348,740,081.37 | 1,051,062,338.72 | 1,437,574,554.31 | 90,384,885.57 | 1,627,889,249.01 | 970,861,089.30 | 2,598,750,338.31 |
| .PRC | PROCUREMENT | 551,776,991.04 | 0.00 | 551,776,991.04 | 0.00 | 0.00 | 23,731,042.48 | 351,399,831.38 | 551,776,991.04 | 903,176,822.42 |
| .MOB | MOBILISATION | 4,584,685.50 | 0.00 | 4,584,685.50 | 0.00 | 4,584,685.50 | 480,575.00 | 235,885,433.00 | 0.00 | 235,885,433.00 |
| .FNS | FINISHING WORK | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9,778,655.68 | 0.00 | 9,778,655.68 |
| .ENG | ENGINEERING | 11,399,238.20 | 0.00 | 11,399,238.20 | 0.00 | 11,311,869.60 | 738,889.84 | 54,468,432.36 | 87,368.60 | 54,555,800.96 |
| .CON | CONSTRUCTION | 1,829,909,848.86 | 52,532,617.61 | 1,770,214,286.63 | 1,051,062,338.72 | 1,410,913,119.21 | 64,613,281.54 | 885,691,672.08 | 418,996,729.66 | 1,304,688,401.74 |
| .CON-DNB | DESIGN & BUILD PORTION | 1,821,747,754.32 | 52,532,617.61 | 1,762,052,192.08 | 1,051,062,338.72 | 1,410,913,119.21 | 60,605,799.02 | 856,504,207.89 | 410,834,635.11 | 1,267,338,843.00 |
| .CON-DNB... | SECT-5:PIR P145-P99 (MAIN LNE-END) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 56,262.45 | 56,262.45 | 0.00 | 56,262.45 |
| .CON-DNB... | SECT-4:PIR P175-P148(DFNSE LND-MAIN LNE) | 148,653,544.71 | 15,476,143.13 | 148,496,691.91 | 0.00 | 0.00 | 37,508.30 | 37,508.30 | 148,653,544.71 | 148,691,053.01 |
| .CON-DNB... | SECT-3:PIR P197-P178 (HRS BRG-DFNSE LND) | 202,676,020.20 | 0.00 | 202,676,020.20 | 0.00 | 0.00 | 0.00 | 0.00 | 202,676,020.20 | 202,676,020.20 |
| .CON-DNB... | SECT-2:PIR P282-P198(NSHK PHTA-HRIS BRG) | 780,787,291.38 | 16,142,767.54 | 724,124,216.65 | 877,290,043.35 | 877,290,043.35 | 36,574,881.71 | 402,902,846.55 | -96,502,751.97 | 306,400,094.58 |
| .CON-DNB... | SECT1:PIR P380 TO PIR BH1(UPTO BHR STN) | 689,630,898.03 | 20,913,706.94 | 686,755,263.33 | 173,772,295.37 | 533,623,075.86 | 23,937,146.56 | 453,507,590.59 | 156,007,822.17 | 609,515,412.76 |
| .CON-DNB... | STATION:VIADUCT | 146,161,621.08 | 0.00 | 146,161,621.08 | 63,578,328.37 | 83,792,841.43 | 1,577,968.50 | 63,105,036.93 | 62,368,779.65 | 125,473,816.58 |
| .CON-DNB... | VIADUCT | 543,469,276.95 | 20,913,706.94 | 540,593,642.24 | 110,193,967.00 | 449,830,234.43 | 22,109,881.76 | 329,302,994.20 | 93,639,042.52 | 422,942,036.72 |
| .CON-DNB... | SUPER-STRUCTURE | 211,751,282.73 | 20,913,706.94 | 208,875,648.03 | 17,169,680.27 | 78,847,457.62 | 13,368,649.83 | 70,026,621.76 | 132,903,825.11 | 202,930,446.87 |
| .CON-DNB... | SUB-STRUCTURE | 331,717,994.22 | 0.00 | 331,717,994.22 | 93,024,286.73 | 370,982,776.81 | 8,741,231.93 | 259,276,372.44 | -39,264,782.59 | 220,011,589.85 |

**Figure 37- Earned Value Management (Maha-Metro, 2017)**

## 5.10. Asset Management

The Asset Information Management solution is required to support the overall strategic initiative of implementing an asset inventory system whilst adhering to the 5D BIM processes that will be applied throughout the full asset lifecycle of Maha Metro within the Common Data Environment. The goal of this is to design, configure and implement an Asset Information Management System (AIMS) to ensure that Employer, contractors and partners are able to register all assets that form part of the Metro rail project and are deemed deliverables prior to handover to operations

### 5.10.1. Overview of Asset Management Process

Asset Management process is capturing asset data from design phase till testing and commissioning phase to help organization effectively manage the assets during Operation and Maintenance Phase. The delivered asset will have asset tag, 3D model, information in the form of attributes, LRUs, maintenance activities & documentation related to the identified assets.

Asset Management Process would help the O&M team to visualize all assets virtually during its operation. This will add ability to foresee the risks & avoid hindrances during operations. Comprehensive Asset Management will ensure more reliability, availability and safety during operations of Metro. In the solution implemented in this project Asset Management starts from the Asset Tag creation in Bentley AssetWise. Further the Tags are updated in 3D models & the various documents, drawings are attached to the Asset Tag in AssetWise during the phases of the project.

Asset Tags are then transferred to SAP ERP system and granular levels of the equipment are managed in SAP for operations, maintenance & reporting such as RAMS, Failure analysis are done. Below figure explains the Asset Management activities and different software involved in process.

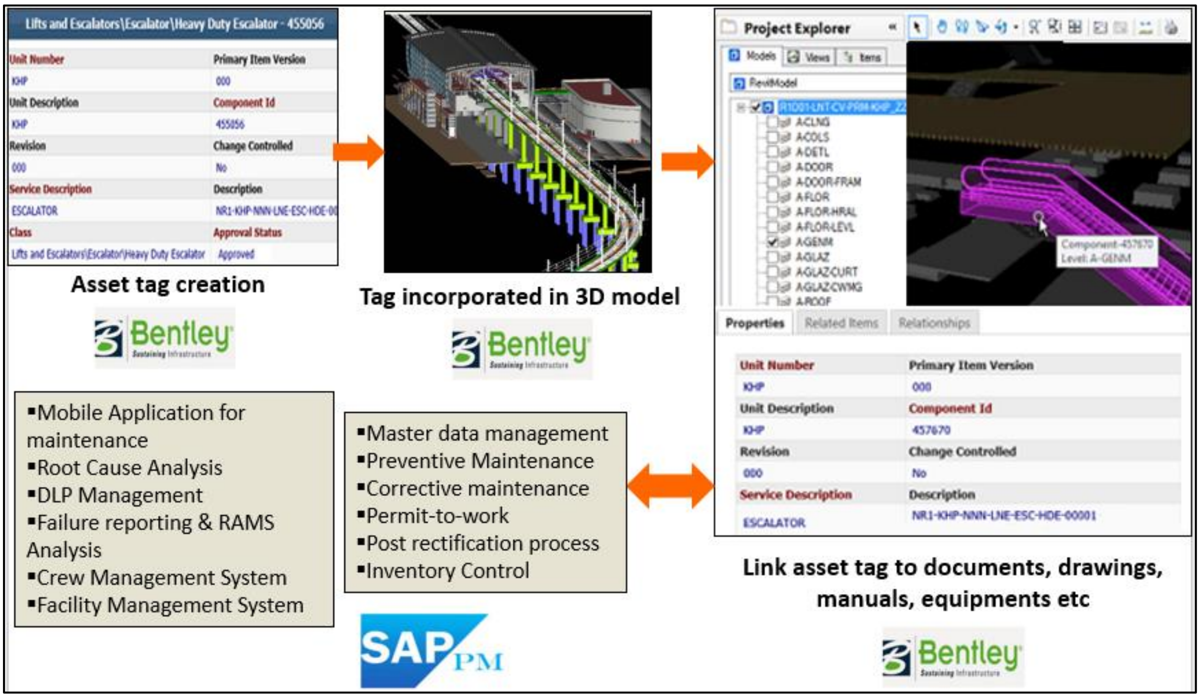



**Figure 38- Summary of Asset Management Process (Maha-Metro, 2017)**

### 5.10.2. Asset Breakdown Structure

Different disciplines generate different types of Assets during execution phase of the project. Asset Breakdown Structure is developed to classify these assets based on their disciplines and type. Attributes of the asset are based on the type of asset and can be configured in Asset Management platform.

If the assets are placed along the length of the alignment of metro, those are identified as Linear Assets. Line assets may not necessarily have linear unit of measurement such as meter, feet etc. Point machines even though having unit of measurement as number is considered to be Linear asset as it is placed along the length of alignment.

If the assets are not placed along the length but located in particular place like station room, it is identified as Point Asset. Below is the Figure to explain how assets from different disciplines are classified.

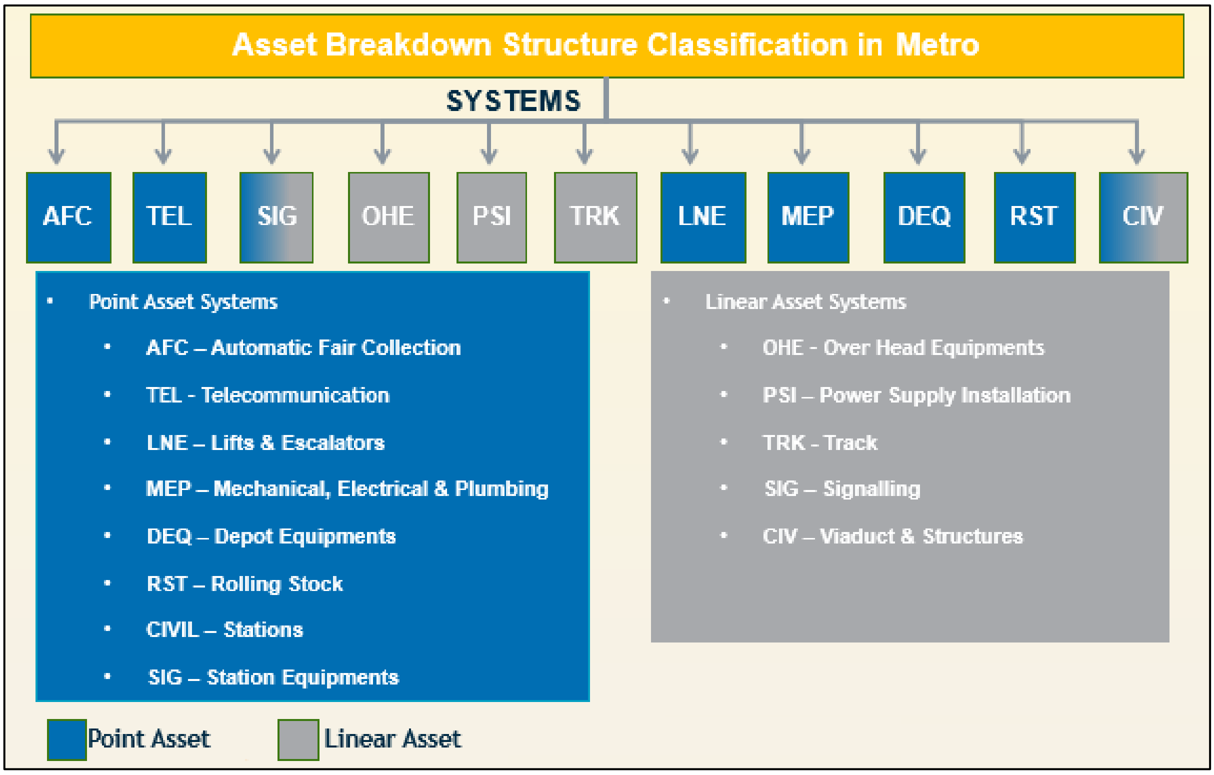



**Figure 39-Asset Breakdown Hierarchy (Maha-Metro, 2017)**

### 5.10.3. Location Hierarchy

Location Hierarchy is a way to organize all Assets based on the placement of any Asset. Maintenance team should be able to easily identify the location of all Assets. For Maha Metro Project, Location Hierarchy is based on the route of transport, Viaduct area or Stations (Location) and Different levels/rooms (Particular Location).


**Figure 40-Example of Location Hierarchy (Maha-Metro, 2017)**

### 5.10.4. Asset Hierarchy

Asset Hierarchy is a way to organize all Assets based on the disciplines and further components of it. For this project, Asset Hierarchy has System at the highest level for any asset. Under particular System there can be multiple Sub-Systems. The Sub-Systems are further divided into numerous Discrete Sub-Systems. These will have Parent-child connections for better identification. Well organized Asset Hierarchy helps maintenance team members to understand and identify any Asset. This forms the part of codification of Asset Tag and created in AssetWise software.

Asset Hierarchy also consists of Assemblies and Least Replaceable Units (LRU) defined for each Discrete Sub-System. The assemblies and LRUs are created SAP software. The LRU (Lowest/Least replaceable unit) in AssetWise CDE might not be the same level of an LRU in CMMS (SAP) and the business was required to define the level required to be identified and managed in the CDE versus SAP e.g.:

CDE – TELECOM/CCTV

VS

SAP – TELECOM/CCTV/PTZC/LENS

Below figure explains the Asset Hierarchy defined for the project.

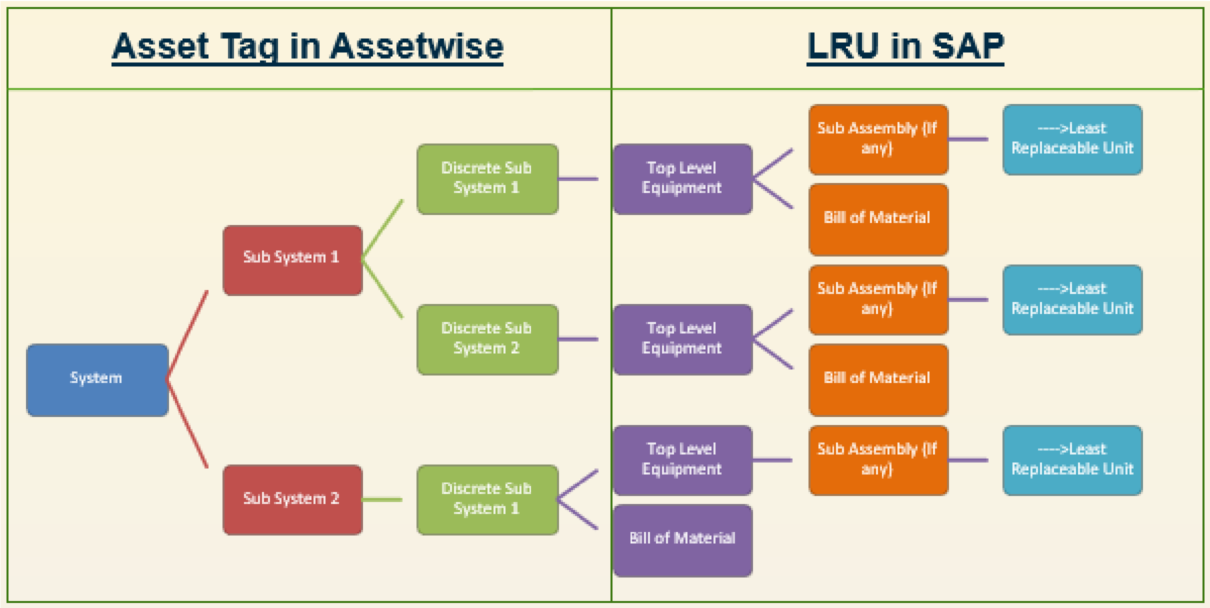



**Figure 41-Asset Hierarchy (Maha-Metro, 2017)**

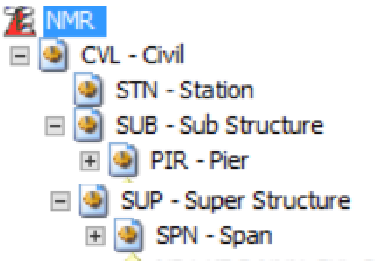



**Figure 42-Example of  Asset Hierarchy (Maha-Metro, 2017)**

### 5.10.5. Asset Tag Codification

Asset Tag is a unique address or identification mark of any Asset. Asset Tag helps to identify the location as well as Systems of any Asset. The asset definition will be captured using a combination of attributes and relationships to functional and location references. The equipment that meets the requirements specified in the asset definition will be captured using a combination of the authorized part, the manufacturer and model and where applicable the specific serial number that has been installed.

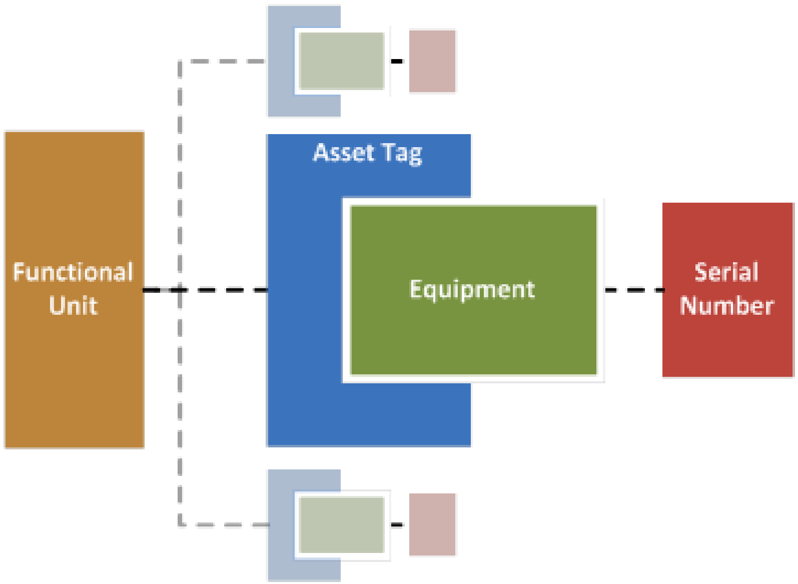



**Figure 43-Composition of Asset Tag (Maha-Metro, 2017)**

For this metro rail Project, every asset is identified with unique Asset Tag. The following Figure the codification defined for Maha Metro Project.

| | Where | | | | | | What | | | | | | Quantity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location Hierarchy | | | | | | Asset Hierarchy | | | | | | Number |
| MMRCL Description | Route Code | | Location Code | | Particular Location Code | | System Code | | Sub-System Code | | Discrete Sub-System Code | | Serial Number |
| | X X X | - | X X X | - | X X X | - | X X X | - | X X X | - | X X X | - | X X X X X |
| Example | P 0 1 | - | V N Z | - | B T R | - | T E L | - | P A S | - | C L S | - | 0 0 0 0 1 |

Where:

| | |
|---|---|
| P01 | Letter represents the Metro City and Digits represent the Route/Line<br>e.g. P = Pune; 01=Line number |
| VNZ | Location Code represents Station/ Viaduct/Depot<br>e.g. VNZ is Station Code for Vanaz Station |
| BTR | Particular Location Code represents the specific area inside the identified Location<br>e.g. BTR is Battery Room inside a Station |
| TEL | System Code is a main System under which Asset is identified like Telecom, Signaling, Track, Civil etc.<br>e.g. TEL is System Code for Telecom |
| PAS | Sub-Systems are identified under main System<br>e.g. PAS is Sub-System Code for Public Address System identified under main System TEL |
| CLS | Discrete Sub-Systems are identified under Sub-System<br>e.g. CLS is Discrete Sub-System Code for Ceiling Speaker identified under Sub-System PAS |
| 00001 | It is a serial number of asset idetified under Discrete Sub-System<br>e.g. 00001 is serial number |

**Figure 44-Asset Tag Classification (Maha-Metro, 2017)**

Asset Tag defined for the project is a code having 23 characters and consists of Location Hierarchy and Asset Hierarchy of the Asset. Each Hierarchy is identified with the code and assigned to Asset Tag. To maintain the uniformity and for better integration purpose, all systems and disciplines to use same codification for particular Asset.

Following is the example of Asset Tag class Breakdown

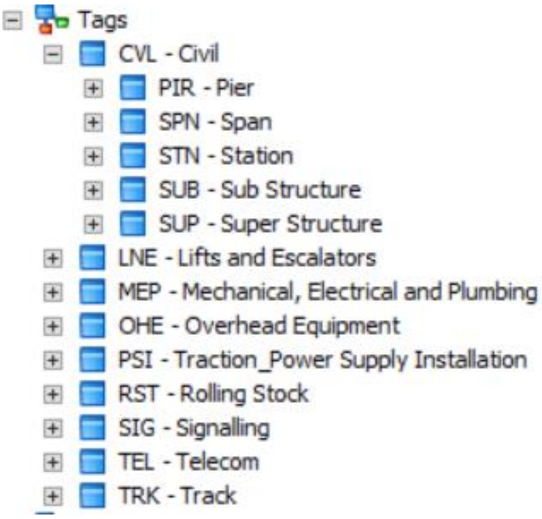



**Figure 45-Asset Tag Breakdown Example (Maha-Metro, 2017)**

### 5.10.6. Asset Attributes

Specific Attributes for each asset tag class were defined by the Asset Information Team(s) as and when the level of asset detail had been determined and agreed based on the specific phase of the project and were assigned to the appropriate asset tag classes using the provisioning spreadsheet.

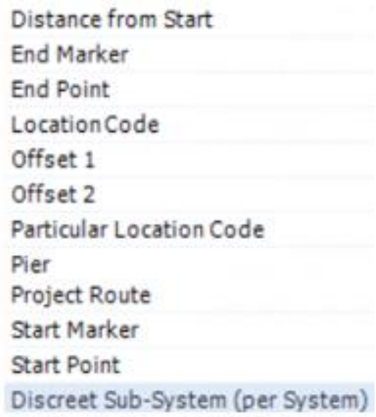
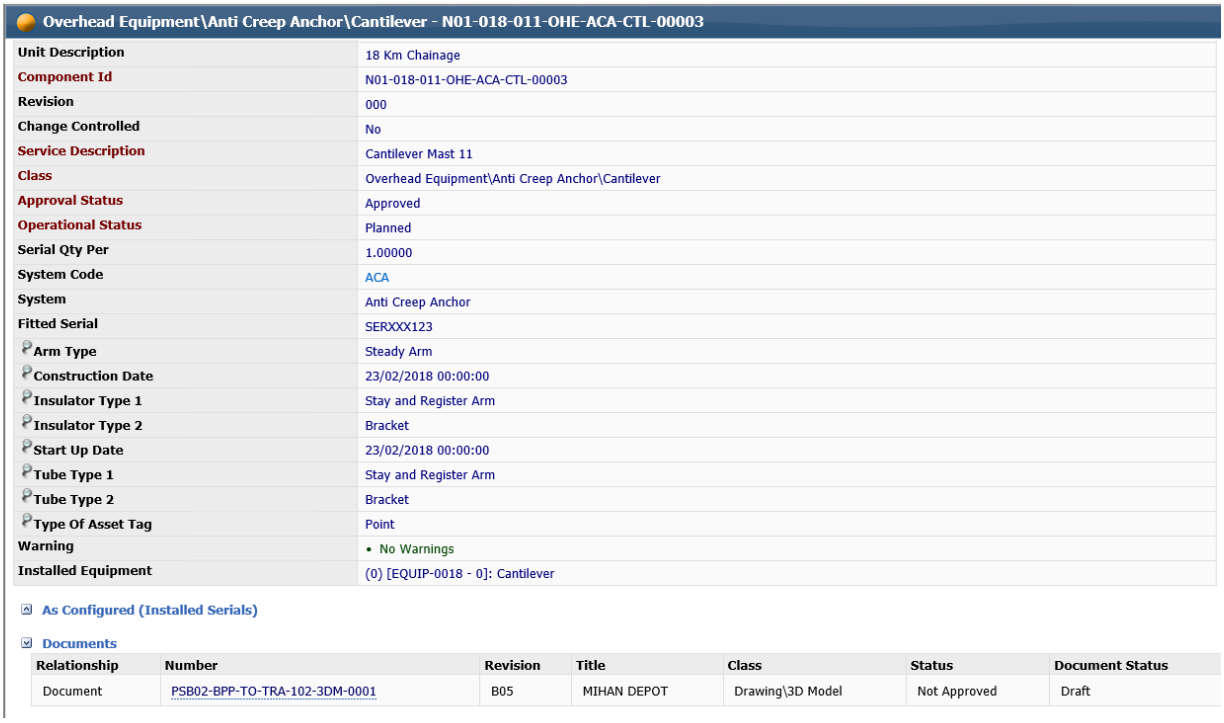



**Figure 46-Asset Tag Attributes Sample (Maha-Metro, 2017)**

Revisions of Tags are essential for managing the evolution of approved changes to the configuration of the Tag by the stakeholders and is therefore used effectively to manage the approval cycles.

The asset tags are integrated with the serial numbers and the related design documents.



**Overhead Equipment\Anti Creep Anchor\Cantilever - N01-018-011-OHE-ACA-CTL-00003**

| | |
|---|---|
| Unit Description | 18 Km Chainage |
| Component Id | N01-018-011-OHE-ACA-CTL-00003 |
| Revision | 000 |
| Change Controlled | No |
| Service Description | Cantilever Mast 11 |
| Class | Overhead Equipment\Anti Creep Anchor\Cantilever |
| Approval Status | Approved |
| Operational Status | Planned |
| Serial Qty Per | 1.00000 |
| System Code | ACA |
| System | Anti Creep Anchor |
| Fitted Serial | SERXXX123 |
| Arm Type | Steady Arm |
| Construction Date | 23/02/2018 00:00:00 |
| Insulator Type 1 | Stay and Register Arm |
| Insulator Type 2 | Bracket |
| Start Up Date | 23/02/2018 00:00:00 |
| Tube Type 1 | Stay and Register Arm |
| Tube Type 2 | Bracket |
| Type Of Asset Tag | Point |
| Warning | • No Warnings |
| Installed Equipment | (0) [EQUIP-0018 - 0]: Cantilever |

As Configured (Installed Serials)

Documents

| Relationship | Number | Revision | Title | Class | Status | Document Status |
|---|---|---|---|---|---|---|
| Document | PSB02-BPP-TO-TRA-102-3DM-0001 | B05 | MIHAN DEPOT | Drawing\3D Model | Not Approved | Draft |

**Figure 47-Asset tag relation with the design document (Maha-Metro, 2017)**

### 5.10.7. Activities, Roles & Responsibilities in the Asset Management Process

This section identifies the activities to be performed by all stakeholders along with their roles and responsibilities. The process involves the creation of Asset Tags right from Design Phase of the project. It is utmost important to start creating Asset Tags as soon as Design is completed for the section. All the Asset Tags to be approved by concerned stakeholders before those are created in AssetWise Software.

Asset Attributes and LRUs: Asset Attributes and Least Replaceable Units (LRUs) need to be defined for all types of Assets. Finalization of Attributes and LRUs were done in consensus with Employer, Employer Representative and Contractor personnel. The process of Asset Management can be defined in the below figure.

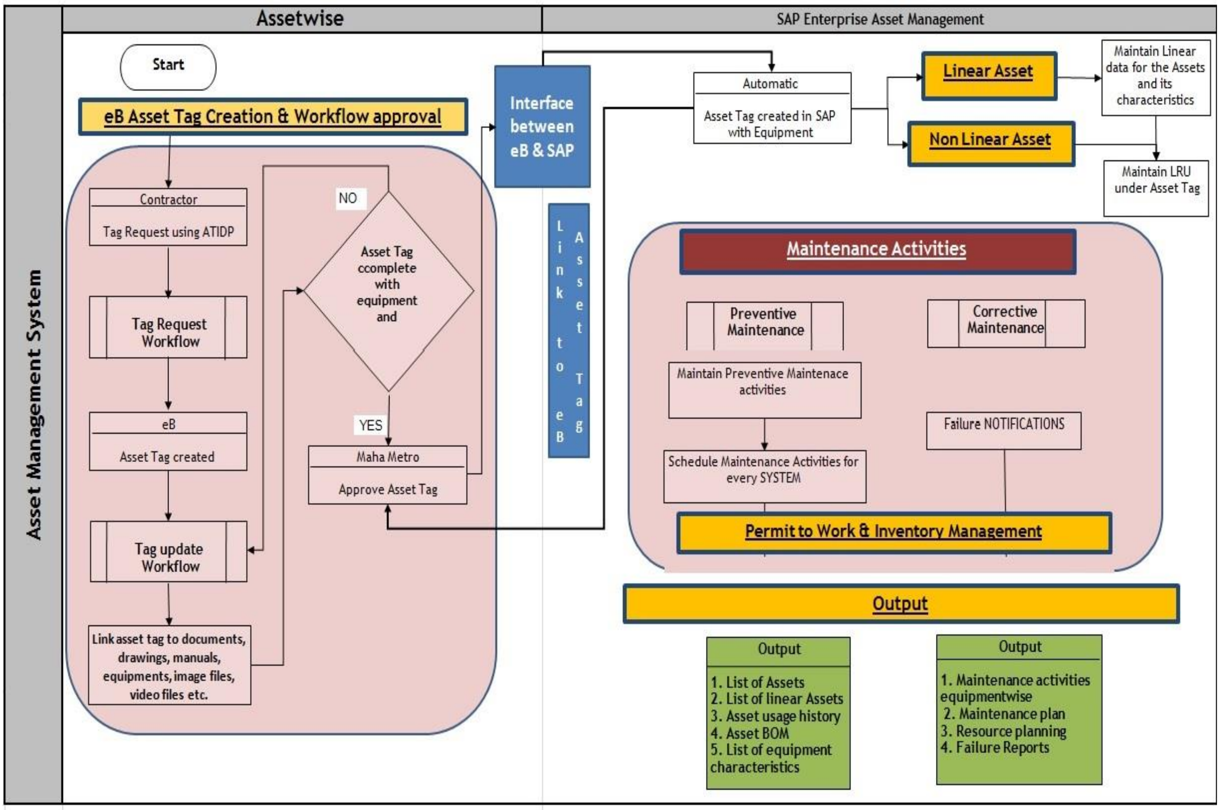



**Figure 48-Process and Activities workflow for Asset Management (Maha-Metro, 2017)**

The figure below presents the business process and workflow adopted for the creation of Asset tags, showing the interaction adopted among different stakeholders for the authorization and approvals.

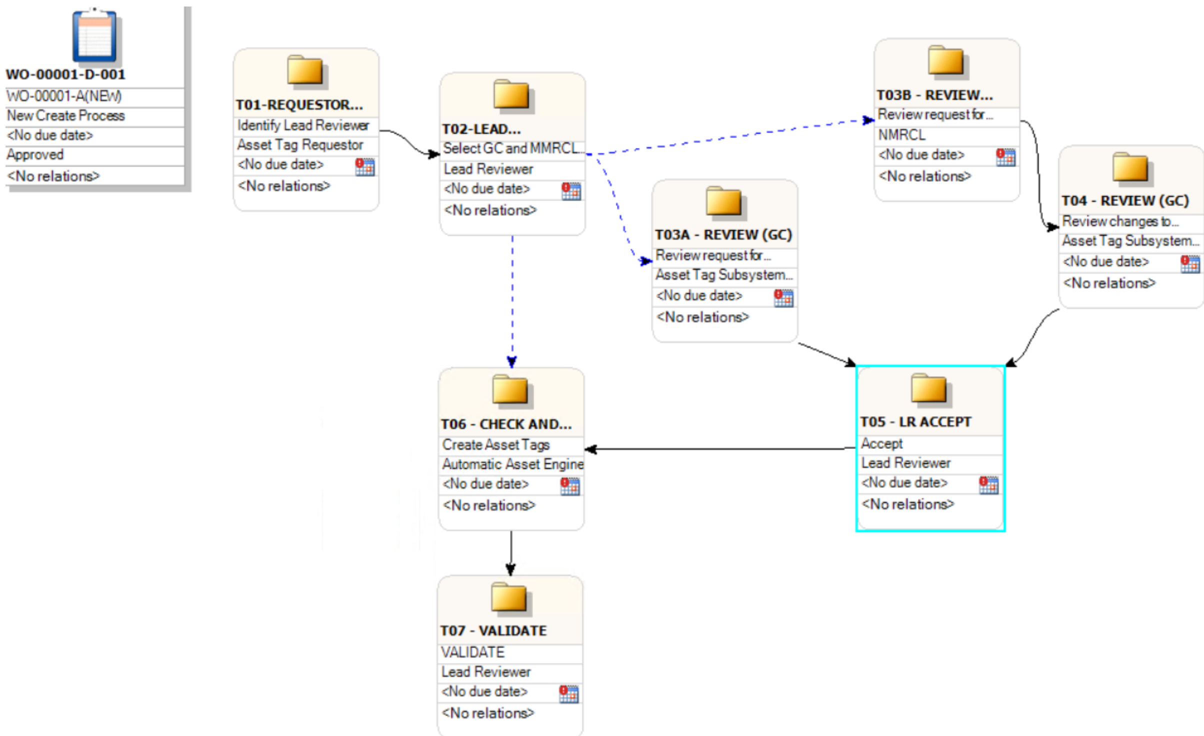



**Figure 49-Workflow for the Asset Creation (Maha-Metro, 2017)**

*So far, more than 500,000 point and linear assets distributed among 12 categories have been created into the platform.*

### 5.11. BIM-enabled Digital War Room

The War room team along with Digital Support team provides strategic support to MAHA METRO to successfully manage the digital platform by continuously monitoring the usage & providing the information to organization Top Management.

It was envisaged that the whole ecosystem of the MAHA METRO i.e. MAHA METRO employees, General Consultants, Detailed Design Consultants, Contractors engaged shall use digital project management platform. Hence, OSO & digital support team plays very important role to ensure that design consultants, contractors, other consultants & employees are carrying out necessary transactions properly in SAP, Primavera & Bentley solutions.

A brief summary of the key areas of work mapped on digital platform operations in the war room are:

- Design & Drawing management – 2D & 3D
- Project Monitoring – Project schedule & progress update
- RA Billing Process – RFI & RA Bill
- 4D Simulation & time progress monitoring on 3D models
- Cost controlling & analysis through 5D project visualizations
- Quality Management – Result recording of material inspection, NCR reports
- Safety – Incident Recording & Investigation, Environmental parameters monitoring.
- Finance & Accounts – Budget Allocation, Expense booking, Fund Inflows & Outflows, Asset Accounting
- Contracts & Procurement – Services database, Work order

The key activities performed in the war room are:

- Provide project management services & establish, manage and own IT strategy and system design
- Monitor execution of project closely, identify bottlenecks and take necessary steps to avoid time & cost overrun
- Monitor alert-based reports and discuss with concerned officers
- Gather vital information from various stakeholders in one place
- Communicate accurate and timely information with key decision makers

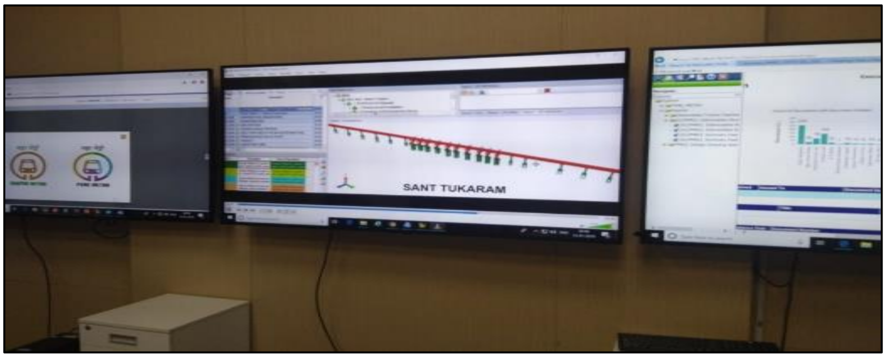



**Figure 50 - Digital War Room: Maha- Metro**

## 5.12. BIM Advancement Academy

The BIM advancement academy is a collaboration between Maha-Metro and Bentley institute to ensure that the best information management practices, for project delivery and asset performance, are adopted by the all the stakeholders of the project.

The Nagpur Maha-Metro project is an assemblage of numerous partners like DDC, GC, consultants, contractors, and other stakeholders that requires extensive synergy and coordination. All stakeholders of Maha-Metro can attend sessions in the BIM Advancement Academy to learn about the technology, data management processes, and principles used across multiple disciplines, and the BIM standards at all stages that are required to deliver state-of-the-art metro projects in India.

The vision of the academy is to create a world- class centre of excellence for rail in India and promote and advance BIM best practices in India. The benefits of BIM advancement academy can be corelated with the improved delivery of projects, through technology advances and improved data mobility, coordinated data management among and between teams throughout the project lifecycle, integrated digital information to improve the physical projects and enforced standards and best practices throughout the entire supply chain.


**Figure 51-BIM Advancement Academy**

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# 6. CONCLUSIONS

Railways is one of the prominent infrastructure sectors which is witnessing large investments for either the upgradations of the existing infrastructure or for the new project around the world in the form of High-Speed rails, urban metro rail systems, cargo lines and the likewise. It is vital that the railway projects are delivered with best class of quality and within the proposed time and cost. Besides the capital expenditures, also as one of the Asset intensive sector, it is essential that the railway project executors work towards minimizing the long term operational and maintenance costs by embracing the digital technologies, which enable congruously the capture of Asset information right from the start of the project. BIM technologies, processes and standards show promising improvements in the delivery of the infrastructure projects both in qualitative and quantitative parameters. To achieve the potential benefits for the adoption of BIM in the railway sector, it is important for the ecosystem to realize the importance of collaborative working, focusing on the recommendations of the international standards. The railway and large-scale infrastructure organizations, which have been able to reap the adoption benefits have identified the role of process change management as a valuable agent.

The dissertation focused on the integration of the railway supply chain which was noticed to be complex, involving multiple interactions among heterogeneous disciplines and participants. The important consideration achieved was the establishment of a well ingrained Common Data Environment (CDE) within the supply chain. As it was adverted to in the work, the client, either the railway infrastructure owner or the project executing authority, are the key enabler for mandating the use of a project wide CDE. The standards ISO 19650, PAS 1192 series and other internationals frameworks clearly and distinctly recommends the Structure, Management and Functionalities of Information containers. and the implementation approach for a prospective CDE solution. Some examples of large railway projects were cited on the literature review and case studies were presented where the strategy for the adoption of CDE and its advantages were analyzed. It was observed distinctly that the CDE was fundamental in the aid for the adoption of BIM in the organization.

It was confirmed BIM as a technological and process enabler for the project information management where the information requirements are the prerequisites. It was confirmed that is critical for the stakeholders to realize that the capturing of the client’s requirements should be identified as one of the first and foremost step in the project process even during the pre-BIM era. BIM can be seen in this aspect, as enabling the digitalization of information and the methods, thus bringing sustainability to the whole process. The mentioned point was considered essential for the change management in the organization where the legacy practices are prevalent. Acquiring and drawing the information requirements was linked to successful delivery of the requirements by the supply chain and also supports the promoter for the future O&M. Information requirements has been identified in the dissertation as the key part of the conceptual framework for the BIM implementation in Railway projects. The different elements of the Information requirements like OIR, AIR, PIR and EIR were considered as the backbone of information management. The structure and the content of the Exchange information requirements are well described in the standards, with lot of possibilities for the project specific customizations. It was noted that identification of the BIM use cases by the client is important, so as to correctly represent the scale of the work, which will help in the avoidance of the information waste and optimize the investment on the digitalization.

The assessment of the competency of the supply chain and its readiness & planning for the information delivery in sync with the Owner’s requirements are considered important. The concept of BIM Execution Plan, along with the content recommendations has been addressed in the work.

Was detailed a case study on the implementation of BIM in substantial voluminous metro rail project that showed the inherent complexity that exists in the railway projects in terms of its scale and multidisciplinary nature. The results of this particular case study testified the framework with the focus on the creation of project wide CDE as the single source of the truth for the information development, delivery and authorization. The CDE worked as the wire, integrating the supply chain of the ecosystem and enabling the quantitative analysis of the design performance through the dashboards. The information requirements were illustrating the BIM objectives and Level of Development were prepared for the entire project and customized for the appointment specific terms. The use of BIM processes for the Asset management was found very appropriate, with the handover of Asset Information Models to the O&M team and further integration with the Computerized Asset Management System (CAMS).

With the increase of stakeholders and it´s global provenience much is yet to be achieved in this Information Management processes to be optimized and more effective in Railway Projects. The so considered conceptual pillars that support this work (Ecosystem, CDE, EIR, BEP) may all be more developed and enhanced in their practical ways of application, with the achievement of proposed templates and platforms.

The integration of all different disciplines may lead to individual design specific interoperable tools, mainly applied to railways. On this subject, the development of Open BIM technologies, taking advantage of the recent extension of IFC for railways and the continuous improvements of the work delivered by a specific workgroup of BuildingSmart International for the linear infrastructure, as well as the COBie Asset formats, are essential.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AEC | Architecture, Engineering and Construction |
| API | Application programming interface |
| BIM | Building Information Modelling |
| CAMS | Computerized Asset Management System |
| CDE | Common Data Environment |
| COBie | Construction Operations Building Information Exchange |
| DDC | Detail Design Consultant |
| ERP | Enterprise Resource Planning |
| EVM | Earned value management. |
| GC | General Consultant |
| ICT | Information and Communication Technology |
| IFC | Industry Foundation Classes |
| KPI | Key Performance Indicator |
| LoD | Level of Detail |
| LoI | Level of Information |
| LRU | Least Replaceable Unit |
| NCR | Non-Compliance Report |
| GIS | Geographic Information System |
| O&M | Operations and Maintenance |
| OSO | Owner Support Office |
| RAMS | Reliability, Availability, Maintainability, and Safety |
| RACI | Responsible, Accountable, Consulted and Informed |
| RA Bill | Running Account Bill |
| RFI | Request for Inspection |
| SGR | Standard Gauge Railway |
| S&T | Signalling and Telecommunications |