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Requirements & Process Analysis for Ports & Waterways openBIM ISO Standards Development

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Structured Abstract

Purpose

Defining Building Information Modelling (BIM) standards for the infrastructure domain is a central issue to the successful implementation of BIM in civil engineering domains. To this end this paper presents a requirements and process analysis for the ports & waterways domain to address the lack of BIM standards development, utilizing the Information Delivery Manual (IDM) approach and the ethos of openBIM standards.

Design/methodology/approach

This research utilizes the Information Delivery Manual (IDM) approach. this involves the definition of use cases, process maps, exchange scenarios and subsequent exchange requirements. All these developments were sourced & validated by a series of international industry consultations.

Findings

The paper identifies 30 domain relevant use cases collated from existing sources and new cases. An overview and detailed ports & waterways process map (defining actors, activities & data exchanges). The process maps highlighted 38 exchange scenarios between various activities. Various exchange requirements were defined and are discussed in the context of the required information exchange model and the extensions required to fulfill the needs of the domain. The analysis provides the core information for the next steps of development for a substantial extension to the IFC and the supporting data dictionary standards.

Research limitations/implications

Because of the international scope of the research the outcomes can be applied by any stakeholders in the domain of ports and waterways. therefore, some variation is expected at a national and organizational level. This research has the potential to accelerate the adoption of openBIM standards within the ports & waterways domain leading to increases in efficiency, collaborative working.

Originality/value

This paper reviews the requirements of an identified gap in the provision of openBIM standards relevant and applicable to the domain of ports & waterways.

1 Introduction

1.1 Overview

The creation of standardized Infrastructure asset & project data throughout the lifecycle of a facility is a key factor for the effective and efficient planning, design, construction, operation & maintenance of the built environment. To this end the application of Building information Modelling (BIM) and its associated benefits is the central paradigm to achieving this 'standardized' data content and process. BIM, as defined by the U.S National Building Information Model Standard Project Committee, "is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition" (National Institute of Building Sciences (NIBS), 2021). BIM is often confused or misunderstood as a 3D model with added features and function, however the 3D model only represents a smaller part of the wider paradigm made up of 4 key elements; collaboration, representation, process & lifecycle which all interact with each other to create an innovative and efficient project environment (Bradley *et al.*, 2016). Using BIM endeavors to provide engineers, managers, constructors, owners & operators with the ability to create, exchange & deliver all required semantic and geometric information., providing a framework to extend industry goals of improving efficiency, quality, and cost of infrastructural projects(Costin *et al.*, 2018).

The following contents are organized as follows. The motivation and aim of the research are given in section 1.2. A background of openBIM standards and other work initiatives is given in section 2. The methodology of the research is detailed in section 3. Section 4 outlines the developed information delivery manual with use cases (section 4.2) and process maps (section 4.3). Section 5 discusses the information structures and requirements need for the domain. The conclusion is given in Section 6.

1.2 Motivation

Currently within the realms of transportation infrastructure multiple stakeholders and studies have been engaged within the areas of road and rail transportation, with earlier work on the common dependent of bridge engineering to provide openBIM exchange standards. In a formal sense BuildingSMART international has initiated projects to provide extensions to their openBIM standards to cover the domain of Road, Rail and a previous project on bridges. Alongside these working groups/communities (known within BuildingSMART as 'rooms') work has begun for the rail and airports domain to organize project work and collaborate/validate within the wider community. These domains address two of the three major modes (land, air & water) of transport for people, goods and services utilized in today's economy.

Sea transportation and maritime structures form a substantial part of the global economy and has been growing consistently over the past 20 years. Total maritime trade has steadily grown from 5.9 billion tons in 2000 to over 11 billion in 2019 (Asariotis *et al.*, 2020). The maritime sector within the UK alone had a direct gross value added (GVA) of £17 billion to the UK economy in 2017 (Maritime UK, 2019). But, despite the massive economic importance and commercial worth, research into the application of BIM for design, planning and management of ports and harbours has been very limited (Costin *et al.*, 2018). Considering this identified gap in coverage of openBIM standards for infrastructure a comprehensive neutral data exchange model capable of representing both the semantic and geometric aspects of a given project or asset and even a portfolio of projects or assets is a requirement for the open data exchange and effective utilization in the context of developing, operating & maintaining maritime infrastructure.

In view of the benefits of the use of open standards, this paper conveys research conducted as part of the IFC for Ports & Waterways project, with the aim of providing a requirements and process analysis for the application of openBIM standards in the ports & waterways domain. To achieve this target, this research conducts Identification, development & validation on (1) information use cases, (2) process maps & (3) exchange model requirements. With the view that the devised use cases, processes & exchange requirements are taken forward and applied to generate an extension of the IFC and supporting standards.

2 Related Work

The growing implementation and expansion of BIM into the infrastructure domain has also led to an explosion of academic work with the wider infrastructure domain. Reviews conducted by Bradley et al. (2016) shows a strong upward trend starting around 2008. This is supported by more recent work conducted by Costin (2018) focusing on transportation infrastructure showing a similar upward trend starting in 2010. Unfortunately, these developments have only be focused on bridges, roads, and highways, providing very limited application to maritime infrastructure.

2.1 OpenBIM standards

Experience has shown that infrastructure projects engage a vast array of actors and branches (or disciplines) of civil engineering, each having different requirements, leading to the development of unique terminologies, data formats and software applications. One of the key pillars of BIM use is collaboration between actors across multiple disciplines, this is hindered by the myriad of exchange schemas, taxonomies, and proprietary data formats each discipline uses to build up the Information model. As a solution to this open BIM standards were developed to provide a neutral open source and comprehensive set of technologies to reduce data rework and software expenditures, plus increase clarity of the whole dataset. The most well-known example of these is the suite of standards developed and maintained by BuildingSMART International which create a core triangle of terminology, processes & digital representations.

1. *Terminology*: different countries and disciplines use their own unique vocabulary, languages and meaning to provide the semantics of concepts within an information model. As a result of this, misunderstandings occur in international and/or multi-discipline collaboration. To improve this BuildingSMART introduced the International Framework for Dictionaries (IFD) standard (ISO23386 (International Organization for Standardization (ISO), 2020)). More commonly known as the BuildingSMART data dictionary (BsDD). At its core it provides mappings, translations, and unified meanings across multiple classification systems, national, project and even company specific standards, providing a singular understanding of terms.
2. *Work processes*: infrastructure structure projects provide a multitude of tasks and process each having a unique purpose and set of input and output information. Such examples include geotechnical design, structural analysis, Design authoring to name but a few. Understanding the flow of tasks, source and use of information, plus responsibility parties for that information is key to the effective application of the BIM paradigm. To facilitate this, need a standard for documenting industry processes was developed called the Information Delivery Manual (IDM) (ISO29481 (International Organization for Standardization (ISO), 2017)). The IDM aims to provide an integrated reference by identifying the discrete processes undertaken, the information required for their execution and the result of the activity (Wix and Karlshøj, 2010).
3. *Digital representations*: to facilitate collaborative working in an environment, an open common information structure is needed to transfer models between proprietary software tools. The Industry Foundation Classes (IFC) (ISO16739 (International Organization for Standardization (ISO), 2013)) is such an Information schema which provides a rigid and authoritative semantic definition of the asset elements and associated relationships, properties, and descriptive information.

All these different standards originate from the buildings sector, this is most apparent in the IFC which before version IFC4x1, only had the ability to represent a building facility. In response to this a consolidated effort has been made to extend BuildingSMART openBIM Standards, into the infrastructure domain. This paper addresses one of those initiatives focusing on the ports & waterways (maritime) domain.

2.2 R&D Initiatives

BuildingSMART international are responsible for the development and maintenance of the openBIM standards and the working groups known as the Infrastructure Room in conjunction with the Rail Room embarked on a suite of development projects to extend the current IFC4 (as of 2013) definition to include infrastructure elements. This included the development of 2 foundational extensions covering alignments for linear infrastructures (2017)(BuildingSMART, 2020a) and staging white paper for the Overall architecture of infrastructure extensions (Borrmann *et al.*, 2017). This was followed by 5 key domains: IFC for Bridges (2019)(BuildingSMART, 2020b, n.d.), IFC for Roads (2020)(BuildingSMART, n.d.; Moon *et al.*, 2019), IFC for Railways (2020)(BuildingSMART, n.d.; IFC Rail Project, 2019), IFC for ports & waterways (2020)(Li *et al.*, 2019) and IFC for tunnels (2021)(BuildingSMART, 2020c). These projects al follow a similar operating methodology to provide the required IFC extensions, work processes and term dictionaries for their domain.

Alongside industry lead initiatives a few academic research initiatives have undertaken work in expanding BIM into the ports and waterways domain. Most notably is the work conducted by Beetz et al.(2015) which uses a lightweight approach to allow the flexible extension of the IFC schema with RDF vocabularies and ontologies. The research uses real-world example quay wall model from the Port of Rotterdam illustrating data from multiple networked data sources integrated with IFC as the main geometric representation carrier. The information examples and application are within the ports and waterways domain but only provide a limited scope of quay walls. In addition, the work focuses on a transition to an approach where IFC files are augmented by RDF triplets and connecting files to the wider linked data cloud. This is a innovative proof of concept but does little to advance the practical implementation of openBIM standards.

3 Methodology

The purpose of requirements analysis encompasses the tasks that go into determining the needs or conditions for a product or project (Kotonya and Sommerville, 1998). In this case, that product/project is the extension and use of openBIM standards for the domain of ports & waterways engineering. The methodology for this requirements analysis utilizes standard methodologies within the BuildingSMART eco-system, the IDM process.

Figure 1 depicts the process employed on the requirements analysis. The initial starting point as with any research revolved around the review of existing exchange standards & work within BuildingSMART and the wider industry. Major standards and reports reviewed for the requirements include:

- BuildingSMART Overall Architecture Report (Borrmann *et al.*, 2017)
- BuildingSMART IFC Bridge Requirements Analysis Report
- BuildingSMART Common Schema Project
- EU Inspire Standards (Hydrography, Water Transport Networks, etc.)
- Uniclass 2015 (January 2020 edition)
- GML Representations (InfraGML, LandXML/GML etc.)

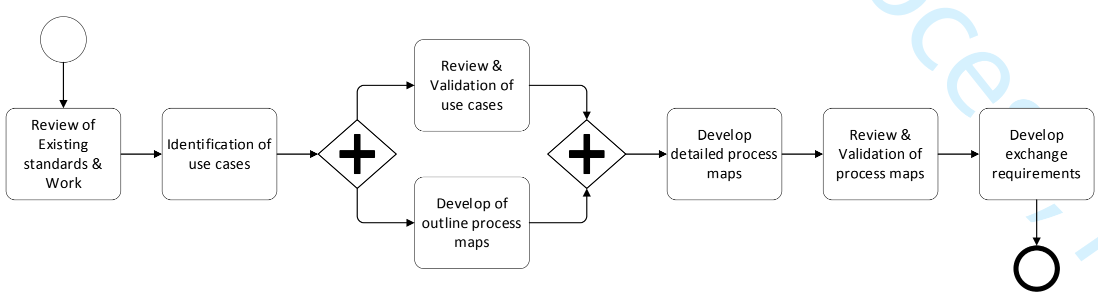

Figure 1 Methodology Flowchart for the development of the Ports & Waterways requirements analysis

The identification of use cases was carried out by first, sourcing the use cases defined by the overall architecture project and the IFC Bridge project. These were then reconciled against each other and documented. Next, domain experts were asked to identify, and document other use cases encountered within the maritime domain until an initial list was developed. Next, a desk review of all use cases was conducted by the core research team using a use case proforma and through workshop sessions each use case was discussed and for future research developments.

To develop a typical Ports and waterways project process map, domain experts were asked to provide/generate their own perspective on the maritime project process. From these organizational/national based perspectives a generic project process was authored and iteratively reviewed until a final version was agreed. As part of the process map exchange scenarios were identified

From the identified use cases and process map the exchange scenarios between tasks and actors were identified and linked to the relevant use cases. To validate these developments an industry wide domain expert consultation was conducted through the medium of expert panels. These provided a forum where the developments were presented to a international audience of experts and invited to comment and contribute to the work. Multiple consultations were conducted during and after the development process.

4 Ports & Waterways Information Delivery Manual

4.1 IDM Overview

An IDM's primary purpose is to capture knowledge and best practices from a domain expert group which can then be presented in a standardized form to aid the application of openBIM within the domain and provide a set of requirements that the digital representation must meet. This is achieved in 3 parts; 1. The definition of use cases, 2. The provision of a process map(s) 3. The identification of exchange scenarios & requirements.

4.2 Ports & Waterways Use Cases

Use cases are a technique for capturing, modelling, and specifying requirements of a system (Bittner, 2003). In this case, the system is the collections of software, actors and working practices employed to reach the goal of designed, built and maintained port & waterway facilities. The planning, design, build & operate process is a combination of primary tasks (use cases) that have a specific function producing an outcome from the available inputs. Within the port & waterways context this could be a berthing analysis to design quay furniture of the birth, structural analysis to check the integrity of a Quay design, or an initial stage use case like master planning which provides the conceptual organisation of the facility aligned with the client requirements. Table 1 shows a summary of the complete list of use cases defined within this research, the focus of the definition is based on the exchange information provided by the actors involved, the purpose of the activity plus the semantic and geometric representation required to conduct the activity.

The use cases identified where sourced from several locations including domain specific new definitions such as mooring analysis, master planning and capacity analysis. It is noted that this research highlights the list of requirements for the openBIM standards, and it is expected that some requirements will already be fulfilled by the existing state of the IFC. This applies to the generic use cases PH03 through PH07 and PH10. These cases are existing functionality within the standard and require review and validation that they are applicable to the ports and waterways domain. Another key concern is that certain new cases are applicable across multiple infrastructure domains (PH18 and PH28) therefore collaboration with projects and experts from domains such as road and rail was required to reach an acceptable definition of the use case.

Table 1 IFC for Ports & Waterways use cases table.

No.	Use case name	Description & Purpose	Required geometry representation	Required semantic information
PH01	Initial State Modelling	Initial data (terrain, soil, existing structures etc.) from various GIS (and other sources) are brought into BIM space and can then be exchanged using IFC to future stages.	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Met oceanographic parameters, Environmental parameters, geology parameters, existing structures data
PH02	Import of Alignment and major Parameters	Alignment and major parameters of the service defined by the alignment (e.g Road, Rail, Breakwater etc) is Imported into a Coordinated model.	Procedural Geometry Alignments & Cross-sections + swept solids	Navigational Channel Parameters Breakwater parameters Other linear shape parameters
PH03	Visualisation	3D technical visualization of the infrastructure project for communication of design solutions within project team and to third parties including the public.	Explicit Geometry Triangulated face sets and/or Boundary Representation	Spatial Structure, Object Typing, Object Relationships Material/Rendering parameters
PH04	Coordination & Collision Detection	Federation of engineering domain models and work segmented models for detection of interferences (clashes), and overall spatial management of the complex.	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Object Typing, Classification Object Relationships
PH05	4D Modelling	4D integration and visualization of construction schedule, to allow optimization and review of construction site & activities.	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Temporal Objects & Parameters, Relationships (Temporal-> Product), Resource Parameters (optional)
PH06	Quantity Take Off (Cost Modelling)	Determine quantities (volumes, surfaces & instances) to generate integrated Bill of Quantities and connected costing model.	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Quantity & material parameters, Cost Object & parameters, Relationships (Cost -> Product)
PH07	Progress Monitoring	Information tracking the progress and completion of the construction schedule to visualise for communication with third parties or conduct earned value analysis.	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Temporal Objects & Parameters, Relationships (Temporal-> Product), Resource Parameters (optional)
PH08	As-Built vs. As-Planned Comparison	Comparison of As-Built/Record model to as-planned models for quality control and construction validation	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Classification, Tolerance Parameters, Object Relationships, Testing Parameters (optional)
PH09	Handover	Development of Delivery Asset Information to Statisfy client and statutory Requirements, has 2 major transport types Asset based (Systems, Zones and Workplans for FM), and GIS based (Navigational Mapping etc.)	Explicit Geometry (All Types) Alignments & Cross-sections	Spatial Structure, Performance, environmental, maintenance, material & manufacturing parameters
PH10	Multi-discipline Design Modelling (Reference Model)	The sequencial and concurrent development of design models, based on the ability to exchange models from concurrent activities or previous stages as a reference model, allowing limited manipulation.	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Design Attributes, Classification, Spatial Structure, Object Typing, Object Relationships, Ultimately dependent on Info Requirements

No.	Use case name	Description & Purpose	Required geometry representation	Required semantic information
PH11	Multi-discipline Design Modelling Full Model Logic)	The sequencial and concurrent development of design models, based on the ability to exchange models from concurrent activities or previous stages as a fully parametric model, allowing full manipulation of model content by receiving application.	All Explicit Geometry, Fully parametric description + model logic, constraints & Dependencies	All Information Present in Model
PH12	Structural Analysis	The structural Analysis of modelled elements such as bridges, retaining walls, wharf platforms, dams & locks. For the purpose of ensuring stability & safety	Analytical geometry and/or procedural descriptions	Material parameters, Loading Scenarios & parameters
PH13	Code Compliance Checking	The Process of reviewing and validating Maritime Structures against international & National codes & regulations	Implicit/procedural description	Regulatory parameters, Dependent on regulatory info requirements
PH14	Drawing Generation	Derivation of drawings and construction documentation that meet local/national regulations.	2D Representation of Explicit and Swept Geometry	All Information for Drawing Representation (including style info)
PH15	Prefabrication & Manufacturing	Use of Model information for the control and automation of production machines, in an offsite manufacturing setting.	Procedural Description (Sweep Geometry, BRep, CSG)	Specific to employed methods
PH16	Energy & Emissions Analysis	Analysis of operable equipment and components in relation to energy consumption and environmental emissions for improvements in operation time & Cost and Master planning of facilities.	Implicit Description (Spatial geometry) + Dynamic Envelopes	Energy & emissions parameters, facility throughput parameters, Operational parameters, vehicle/plant parameters
PH17	Capacity Analysis	Preparation of the spatial, physical and process information for capacity simulation.	Implicit Description (Spatial geometry) + Dynamic Envelopes	Spatial & Connective Relationships, facility throughput parameters, Operational parameters, vehicle/plant parameters
PH18	Geotechnical Design & Analysis	Analysis and Design for geotechnical components involved in the modification (Cut & Fill), Strengthening & creation of Geotechnical elements.	explicit Geometry Boundary Representation, topographic surface representation	Classification, quantities, tolerance & uncertainty parameters hydrology parameters
PH19	Master Planning	The Representation of the initial spatial structure of the Port and Facilities. Includes the concept of Optioning the different scenarios and layouts. Draws information from capacity and existing state modelling. Forms the most effective general arrangement and operational model	Implicit Description (Spatial geometry) + Dynamic Envelopes	Spatial Structure, operational parameters, Performance parameters object relationships, facility throughput parameters
PH20	Fluid Mechanics Analysis	Analysis and decision making around the fluid effects on maritime structures for effective & efficient design of structures.	Analytical geometry and/or procedural descriptions	Material parameters, Met oceanographic scenarios & parameters
PH21	Mooring Analysis	Design and Analysis of mooring strategy to improve productivity and operational efficiency using model information for planning a vessel's mooring arrangement and assessing the adequacy of a terminal's mooring facilities.	Analytical geometry and/or procedural descriptions	Operational parameters, vehicle/plant parameters Met oceanographic scenarios & parameters,
PH22	Model Aided Machine Control	Using model information to assist site construction, and the driving of onsite manufacting machines such as paving layers etc.	Procedural Description (Sweep Geometry, BRep, CSG)	Specific to employed methods

No.	Use case name	Description & Purpose	Required geometry representation	Required semantic information
PH23	Wave Impact Analysis	Using model information for wave Impact analysis, such as breakwater strength and overtopping, to improve or validate design.	Analytical geometry and/or procedural descriptions	Material parameters, Met oceanographic scenarios & parameters
PH24	Navigation Analysis	Usage of model information for navigation analysis. To check the operational navigation of Port in addition to visibilityand distance checks for navigational marks and beacons.	Analytical geometry and full Explicit Geometry	vehicle/plant parameters, Met oceanographic scenarios & parameters,
PH25	Logistic Planning Simulation	Usage of model information for logistic planning simulation. It can be used for; evaluating capacity of container yard, assessing the efficiency of horizontal transport vehicles, port loading and unloading equipment, and berthing number calculation.	Implicit Description (Spatial geometry) + Dynamic Envelopes Explicit Geometry (Any types)	Spatial & Connective Relationships, facility throughput parameters, Operational parameters, vehicle/plant parameters
PH26	Risk Assessment	Use of model information for risk evaluation, e.g. assessment of fire safety and evacuation routes. It can be used for smoke and fire propagation, planning of escape routes, impact of fire on the structures, simulation of traffic flow.	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Material parameters, Met oceanographic scenarios & parameters, Operational parameters
PH27	Ship Lock Operation	Usage of model information for operation, e.g. ship lock operation.	Explicit Geometry with multiple context-based representations	Operational parameters, Kinematic parameters
PH28	Dynamic structures and vehicles	Analysis and Design for dynamic structures, including locks, pontoons and docks and including vehicles and cargo. Illustration and Detection of conflicts and operational issues.	Explicit Geometry with multiple context-based representations	Operational parameters, vehicle/plant parameters, Kinematic parameters
PH29	Digital Twin	Usage of model for creation of Digital Twin - focus on monitoring of performance of the infrastructure	Explicit Geometry Faceted Boundary Representation, Swept Geometry where applicable	Operational parameters, Automation & Control parameters
PH30	Operations & Maintenance	Usage of model for planning of operations & maintenance tasks along with the storage and transfer of inspection data	Explicit Geometry with multiple context-based representations	Inspection entities with associated Parameters, Associative relationships

4.3 Process Maps

To fully understand the requirements for a ports & waterways project and how the use cases outlined in section 4.2 are applied in a typical lifecycle process map is vital. To author the diagrams the Business Process Modelling Notation (BPMN) (Object Management Group, 2011) was used. To manage the complexity of the development process and the readability of the diagrams, two levels of process map where developed, an overview map and a larger detailed process map.

The development started by bringing together existing and authored examples from domain experts who conveyed their knowledge and experience into process models. From this dataset, a list of project stages was identified and adapted to fit an existing international framework. This was the stage definitions set out by the Construction Industry Council detailed in Table 2. These provided the framework for the lifecycle of the process. Additionally, a set of 7 high level actor groups were defined by the AECO services that engage on a typical project to provide the actor swim lanes on our diagrams, these are detailed in Table 3.

Table 2 CIC Project stages definition

Stage	Name
CIC 0	Strategic Definition
CIC 1	Preparation and Brief
CIC 2	Concept Design
CIC 3	Developed Design (or Definition)
CIC 4	Technical Design
CIC 5	Construction & Fabrication
CIC 6	Handover & Commissioning
CIC 7	In-Use

The stages and actor groups were used to produce the overview process map (Figure 2) with the goal of providing the whole picture of the project and asset lifecycle in the maritime domain. The map is structured from task blocks for each of the stages 0 to 7 added to the swim lanes of each actor group that participates within that stage. Where a stage involves 2 or more groups each swim lane gets a task block which encompasses their sub- tasks for that stage and the collaboration flow is illustrated via bidirectional message flows. For example, 2 task blocks are labelled CIC 1 (Preparation and Brief), the first conducted by the Client & Operator services group, encompassing the brief authoring and information requirements tasks for the project. These activities trigger the beginning of the design & engineering services CIC 1 task block which is the authoring of the response to the brief and information requirements. The same can be seen for the CIC 3 task blocks which trigger the involvement of construction services.

The overview process map also shows the relationship between the use cases and the task blocks they are involved in. For example, the PH03 Code Compliance use case can be seen related to the planning & approval tasks conducted by the Regulator actors. To further utilize this use case mapping the overview map abstracts out the analyses tasks in to a specialist actor group name analysis services. This serves 2 purposes; 1) to provide the visual association of the analysis use cases with their relevant stage and 2) excludes the need to include analysis tasks on the detailed process map which would increase the complexity and reduce the readability of the detailed process map due to the iterative design process providing context and decision points to major design areas. In addition, detailed definitions of the use cases developed by this research each have their own documented atomic process map.

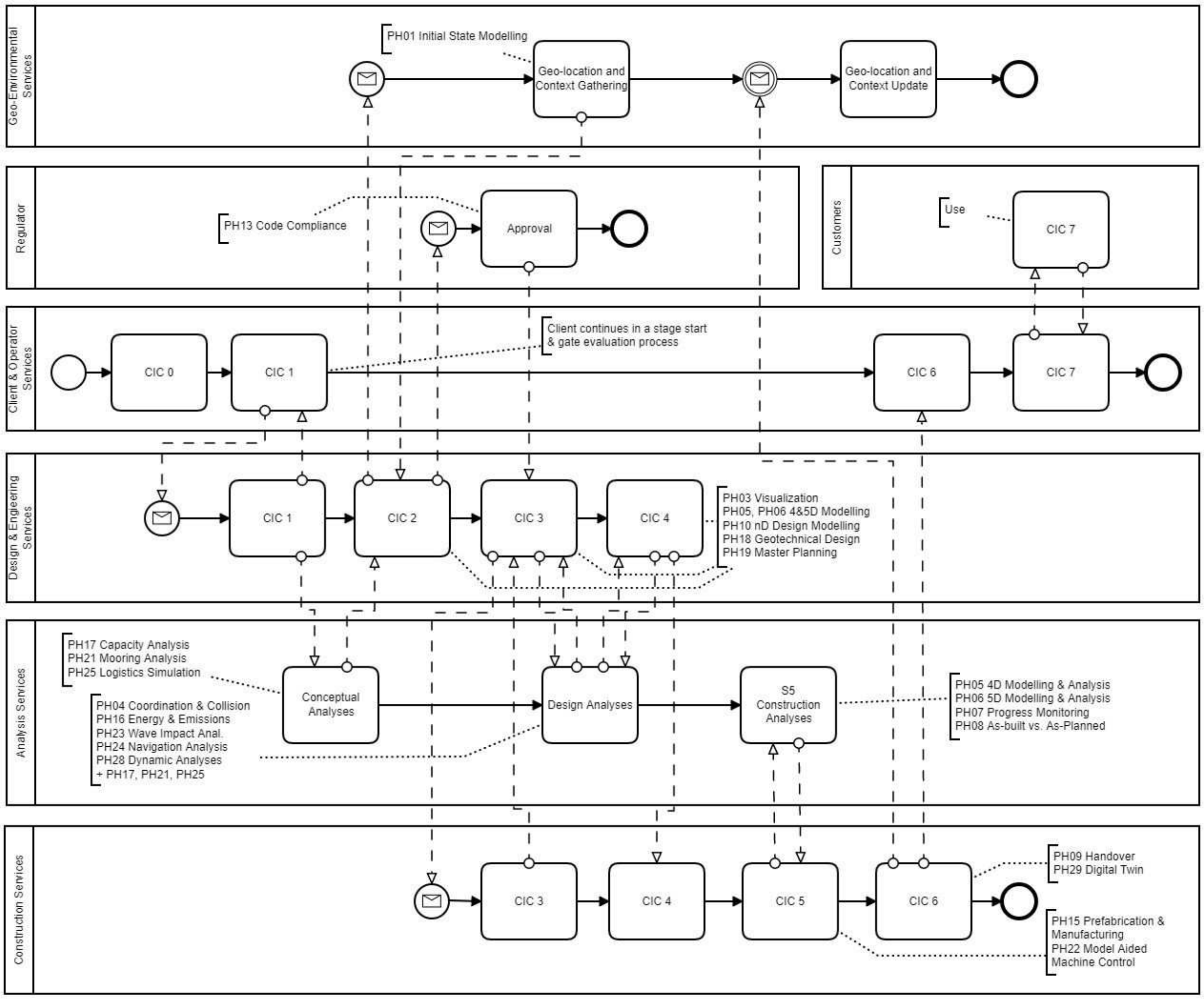

Figure 2 Overview Process Map

From the main skeleton of the overview process map a detailed ports & waterways process map was derived taking in to account the specialist roles such as master planning, maritime engineering and expanding the Initial state modelling process. the full detailed process map is provided as an appendix (Figure 11) to the article. The process map itself is the culmination of multiple regional/national and organizational work practices from around the globe. As this is designed to be universal deviations in national or regional processes are possible, but it is assumed that the general structure and meaning will remain consistent throughout.

The detailed process map takes the previous actor groups and expands them into the full list in Table 3 and defines the entire process of a typical ports & waterways project from stage 1 preparation and brief to entry into the stage 7 operations and use cycle. The detailed map breaks down the lifecycle process to individual tasks that produce some sort of exchange model/file or conducts some sort of analysis, decision gate or approval. To this end the detailed process map enables the identification of the exchange scenarios that take place during the lifecycle of the project/asset. Each exchange scenario contains an exchange model whose content satisfies the outputs from the producing task and the input requirements of the consuming task(s). In total 38 exchange scenarios were identified and documented, these range from the exchange of survey models and engineering design models to berthing analysis and structural analysis models. These scenarios are linked to their respective input and/or output use case, with some scenarios serving more than one use case.

Table 3 Port & Waterways identified actor list.

Actor group & actors			
Geo-Environmental Services		**Design & Engineering Services**	
	Surveyor		Master Planner
	Environmental Engineer		Cost Engineer
National/Regional Regulator			Schedule Planner
	Regulator		Geotechnical Engineer
Client & Operator Services			M&E and Control Engineer
	Owner/Sponsor		Maritime Engineer
	Project Manager	**Construction Services**	
	Operator		Construction Contractor
	Inspector		Fabricator
Analysis Services			Design Capture Team

The detailed process map overall is divided into stages. Once a batch of relevant tasks are completed for the stage the flow converges to a stage gate review task conducted by the owner/sponsor where a continue, redo, or terminate decision is made. The next stage is then initiated by a stage start task which branches out to trigger the relevant actors. Figure 3 depicts an expanded version of this gate where the flow varies depending on when the constructor tendering process takes place.

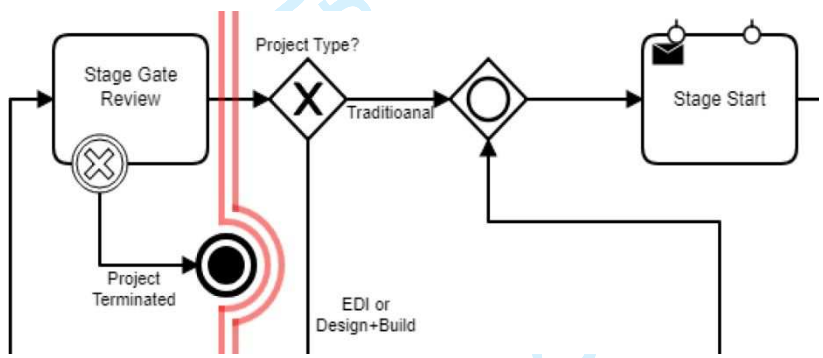

Figure 3 Excerpt from ports & waterways detailed process map highlighting the stage gate for CIC 3 to 4

Lastly the detailed process map represents the combination of blocks associated with different use cases. For example, the excerpt in Figure 4 depicts the CIC stage 3 activities which make up most of the initial state modelling use case. Upon the initiation of the stage, the owner/sponsor engages the actors within geo-environmental services group to begin the process of conducting environmental, topographic, bathymetric, meteorological, and oceanographic surveys. Through the included data processing these survey tasks culminate in an initial state model (IE06), a flood risk assessment (IE08, if required) and environmental social & health impact assessment (ESHIA IE07). This case also illustrates the initial state model as a federation of the environmental, geotechnical and survey models. This collection of outputs are provided back to the project as deliverables and used as inputs into the subsequent Preliminary design tasks conducted by the geotechnical & maritime engineers.

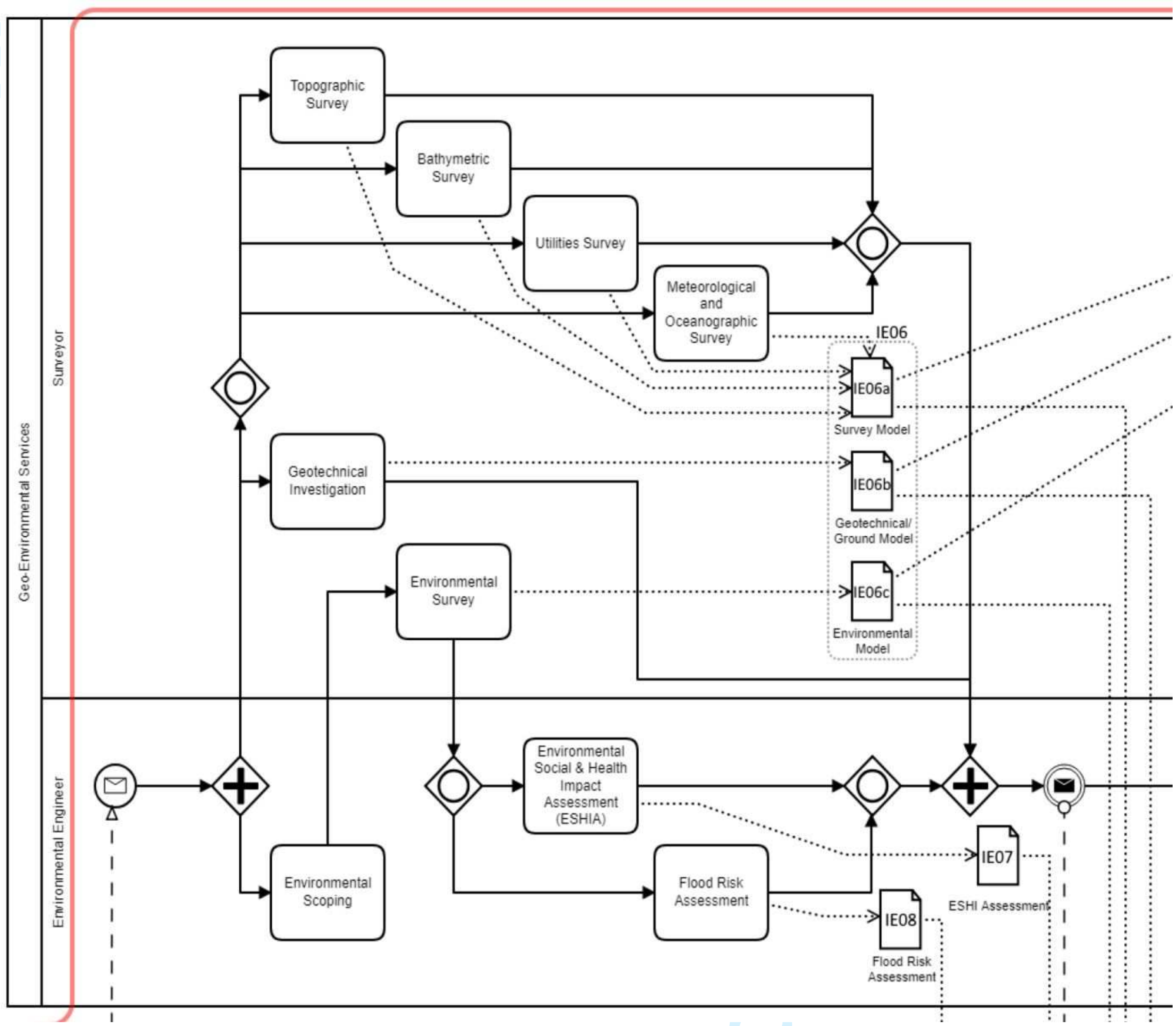

Figure 4 Excerpt from the Ports & Waterways detailed process map focusing on initial state modelling.

It is emphasized that this detailed process definition does not account for every eventuality, it attempts to define a common and generic map with deviations possible in extenuating or unique circumstances. For reasons of complexity and readability certain process blocks and constructs that routinely take place in the lifecycle of a project have been omitted from the detailed process map. Notable omissions are:

- Document/model approval
- Iterative design development & Feedback

Document/model approval is a key process block within the project development for purposes of quality assurance, validation, and safety. It is implied that when tasks produce exchange models, these outputs (or deliverables) go through the required checking, approval, and issue process according to national standards and industry best practices. This could involve the subsequent revision of outputs and the repeating of work. Due to issues of size and readability of expressing feedback and revision loops for each model production task, this process is assumed to form a repeatable part of the model production method.

Iterative design development & feedback is an important construct within modern engineering practices, with reduced review cycle length and improved efficiency being some of the central advantages of modern information modelling practices and software platforms. Therefore, it is implied that an iterative development cycle is used within the bounds of each design stage before culminating in an approval and issue of deliverables and a stage gate review by the client. The sequencing of the process map is intended to depict the dependencies of tasks conducted by different actors. For example, sequencing places the master plan development before design tasks by the geotechnical engineer & maritime engineer (which can be done concurrently), with the M&E development following the maritime engineer's work. In reality, elements discovered in the geotechnical and maritime design development will feed back into the master plan to further improve the solution, in the same way that the M&E design after the initial lag will develop alongside the maritime design elements and provide feedback to improve both parts of the solution. In addition, an iterative process is present within the inspection and review of assets during the operational phase, which in turn leads to the activation of future major and minor projects. Due to the complexity and resulting poor readability of depicting this iterative process, a dependency-based sequencing and 2 stage model federation is used to convey the process and exchange scenarios.

5 Information Structures & Requirements

Exchange requirements represent the link between data and process (Wix and Karlshøj, 2010) determining the correct & required data exchange to conduct the next task. With this comes a need for a data standard (an exchange format or schema structure), currently these exchanges are achieved through multiple exchange formats such as IFC4, LandXML, GeoSciXML etc. plus proprietary native formats that lock stakeholders into specific software suites. This brings us back to the earlier primary need for an open neutral data standard for the exchange of infrastructural information. IFC would currently be the best placed standard to fulfil this need, but it requires substantial extension to meet this function. To that end using the earlier use cases and process mapping, this research lays out the requirements of the extension of IFC to be implanted as the standard for exchanges highlighted during section 4.3.

5.1 Information Structures

The structure of information is vital to the meaning of the developed data and allows the efficient transfer and understanding between parties. It is understood that there are several ways to structure information within the current IFC schema and the wider requirements of the ports & waterways domain. These structures exist concurrently and serve different purposes within the dataset.

Within the ports & waterways domain (and often in other domains) 3 primary structures were highlighted as requirements which are depicted within Figure 5.

- *Spatial*; for the breakdown of locations forming the functional areas and placement hierarchy.
- *Physical*; forming the hierarchy of physically built components and functional facilities and networks.
- *Process*; forming the expression of construction, operational or environmental processes within a wider strategy.

Current functionality allows for the representation of the lower 3 layers of our structure requirement, allowing the representation of a site, facility (aka a building) and project. The requirements for ports & waterways need this to be extended to include further top-level strategic entities to represent spatial, physical & process aggregation of sites, facilities, & projects, for wider operational and portfolio management tasks. For example, the aggregation of sites into uniform catchment allows the management of multiple discrete sites within a wider system, such as that used by the Environment Agency in the United Kingdom, to manage river catchments with multiple flood protection and water management sites within. This could be achieved using existing mechanisms within the IFC but lack the correct semantic definition and associated attributes. In addition, there is a requirement to represent an entire port/waterway complex as a singular coherent entity for both asset management and design, hence the definition of a complex as a group of built/managed facilities is required (further description and an example can be found in section 5.2).

Though the currently held view of the IFC dataset, is that a single instance of IfcProject provides context of data for an exchange. Such exchanges are typically limited in size and duration. Therefore, it is not expected that an entire complex or network structure will be exchanged, but to maintain consistency and relationships between the central model repository (or asset management environment) that holds multiple sites, facilities/complexes and projects a coherent representation is required within the IFC schema, if not mandated within the exchange definition. Also, in relation to asset management systems the physical hierarchy will form the primary representation for the asset breakdown structure when transferring to the central repository.

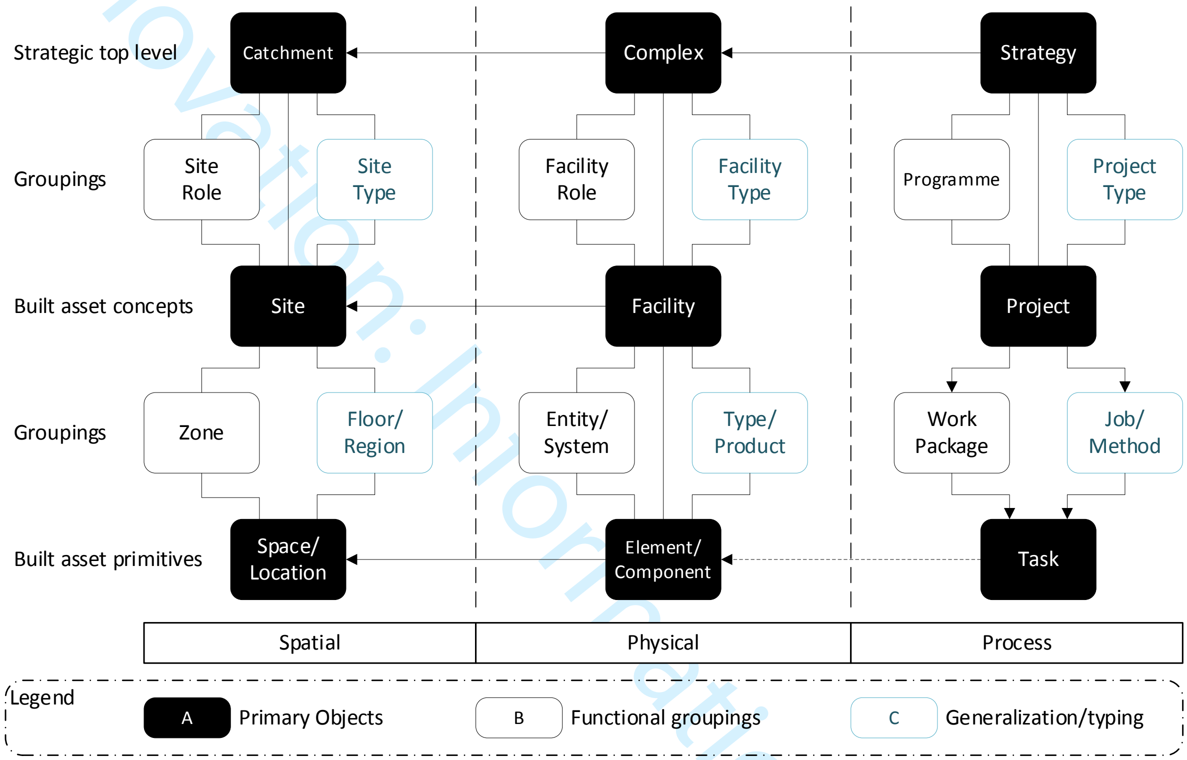

Figure 5 Primary breakdown structures for ports & waterways (Li *et al.*, 2019)

5.2 Spatial Requirements

In construction, engineering and operation facilities are often spatially decomposed to provide a logical organization hierarchy for placement, property association and early design definition. For example, it is common to decompose buildings into storeys and spaces from the initial design phase. Within IFC, only building decomposition is explicitly defined, and utilizes a basic structure of:

Site → Building → Storey → Space

This aligns with the structure in Figure 5 where the facility is of sub type *'Building'.* The initial generic spatial breakdown structure put forward by put forward by previous research (Borrmann *et al.*, 2017) resembles a generalized breakdown using a '*Facility*' with a '*Facility Part*' (Figure 6). The structure is split between the spatial object (blue) and the physical objects (orange), the connection between these represent containment within the upper spatial entity usually for organizational and local placement purposes. The requirements of ports & waterways (Figure 7) call for the addition of a top-level entity within the spatial hierarchy to allow the grouping of multiple facilities under one coherent '*Complex*', this theoretically could exist as a specialization of the facility object. Also, it is suggested that 'Region' be utilised instead of part as part implies a physical block. To reconcile between the figures below and Figure 5 presented earlier it is understood that 'Facility' & 'Complex' are physical elements but can also act as spatial elements within their respective decompositions allowing duality between the placement and asset structures. It expected (but not required) that spatial elements delimit a physical or notional boundary and can adapt a local placement mechanism to allow modular design development. Like the need to aggregate multiple facilities into a complex or network, IPW requires the ability to breakdown projects and/or catchments into multiple sites to allow for both work division and management.

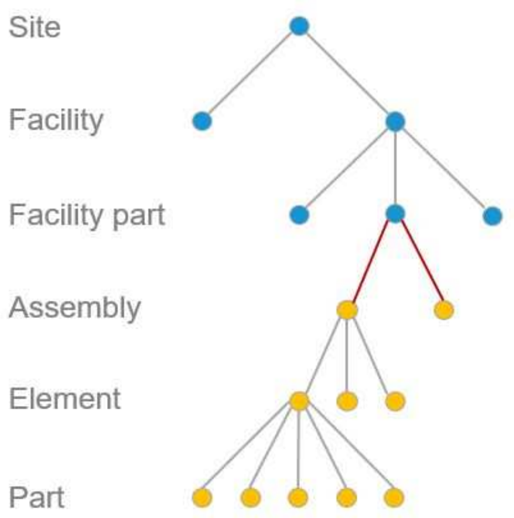

Figure 6 Common schema generic spatial breakdown

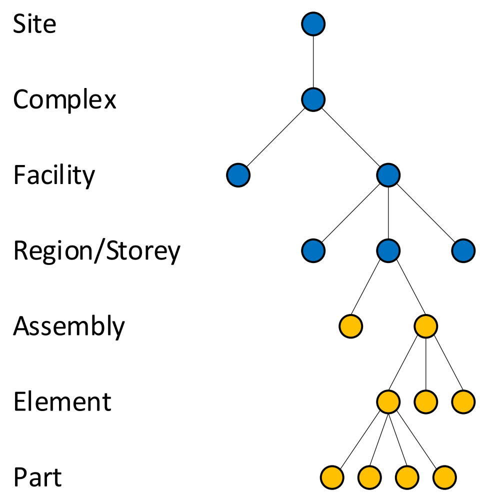

Figure 7 Ports & waterways spatial breakdown requirement

To illustrate this breakdown Figure 8 shows an example of a container terminal complex, the complex is made up of multiple facilities such as the container stacks, quay, internal & external roads, administrative buildings etc. These facilities break up the functional areas of the complex and form a process system with serving /served connections and performance/capacity ratings.

It is expected that the minimum spatial requirement for ports & waterways match that of the building structure to enable compatibility with existing applications. This implies the simplest structure of:

One site → one facility → one facility region → one space/location

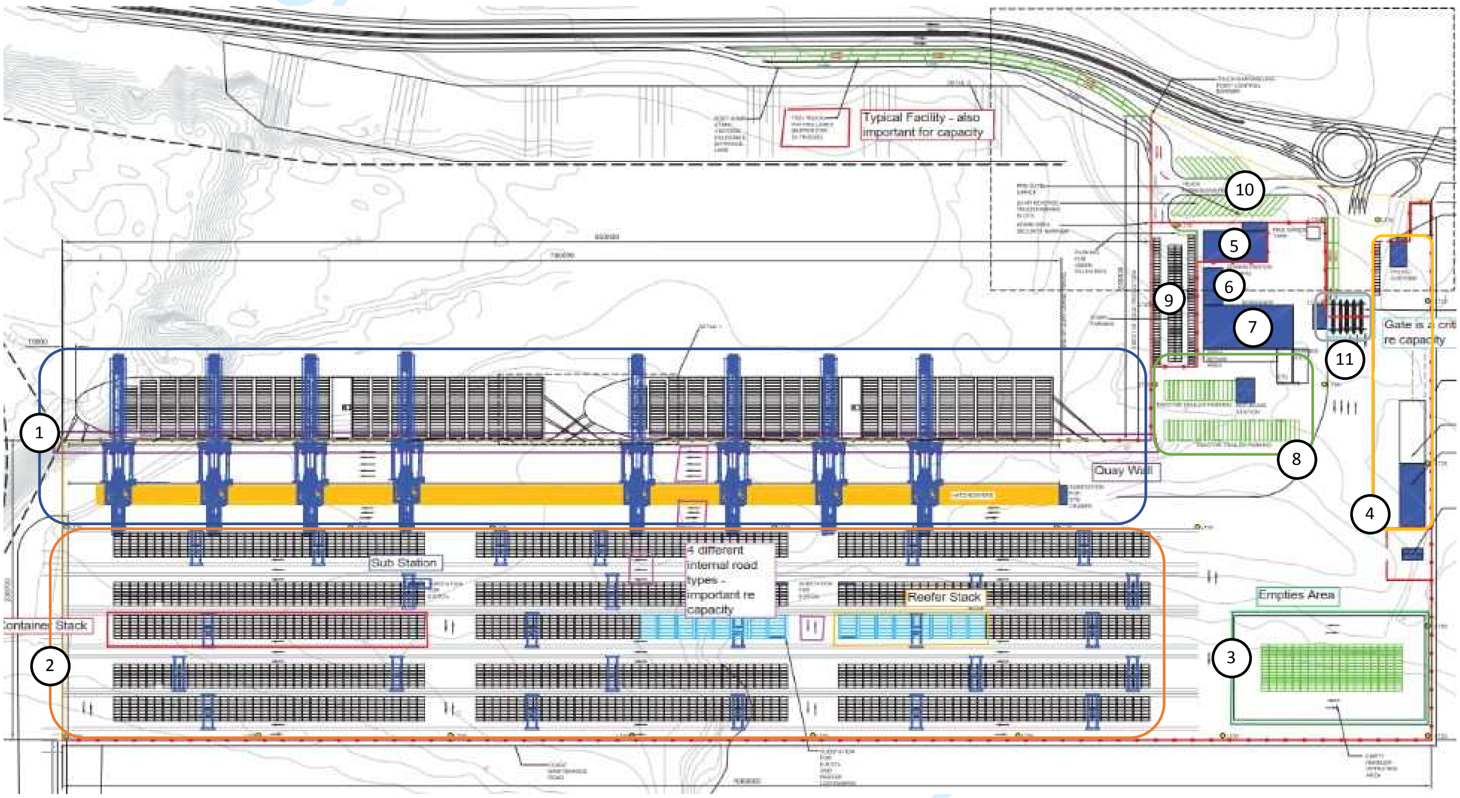

Figure 8 Ports & Waterways Container Terminal Spatial Breakdown

Table 8 Legend for Ports & waterways container terminal spatial breakdown

Container Terminal Complex Facilities	
1	Main Quay
2	Container Stacks
3	Empties Area
4	Customs & Police Facility
5	Administration Building
6	Power Station
7	Workshop
8	Tractor Trailer Service/Storage
9	Staff Parking
10	Truck Parking & Waiting
11	Entrance Gate

5.3 Asset Management Requirements

To support a fuller spectrum of asset management than previously documented in openBIM standards these requirements seek to expand the current functionality by addressing non-product assets, such as the complex, the discrete facilities within the complex and the functional systems. In addition, these requirements address the provision of new technologies such as Internet of Things (IoT) within the maintenance strategy and the requirements for the exchange of their physical and logical information.

1. Asset Prioritisation: These non-product assets will be assigned properties that document their significance to the commercial and operational effectiveness. The prioritisation of assets may be provided by the client or by the design and engineering team, based on its overall criticality and its vulnerability to degradation.
2. Monitoring policy: The prioritisation may affect the choice of monitoring policy. These may include using IoT (internet of things), day usage, hour's usage, inspection, or reactive reporting.
3. Capacity and Performance: Such monitoring may measure or assess the capacity and performance of the non-product assets. In particular, the systems specific to ports and waterways will be reviewed to identify the characteristic capacity or performance measure. Properties should document the briefed or specified capacity and performance, anticipating that actual or supplied capacity and performance will become known during construction and use. Operational policy decisions may then set the trigger levels for replacement, maintenance, or inspection.
4. Other impacts: To support the development of comparisons and benchmarks for non-product assets, served/serving measurers and other social, economic and environmental impacts will be documented.
5. Process modelling: To support the assessment of the overall capacity of port and waterway complexes, systems of vehicles and transport will be related to zones in served/serving relationships. Basic capacity and time parameters for systems and zones will be documented, so that third party applications will be able to perform either mathematical or probabilistic analysis. The same information may be used to populate 'Terminal Operating Systems'.

6 Conclusion

The primary goal of this paper was to conduct a requirements & process analysis for the application of openBIM standards I the ports & waterways domain. The research adopted the well-known information delivery manual (IDM) methodology involving the collaborative definition of (1) information use cases, (2) process maps & (3) exchange models requirements. 30 use cases in all were defined, 14 are new cases with the rest derived from previous works. These use cases provide the base from which project tasks can be organized information input & output requirements defined. From these use cases 2 process maps were authored providing an overview of the project/asset lifecycle and a detailed process flow identifying a total of 38 individual information exchange scenarios, conducted by 7 distinct actor groups containing 18 actor roles. From these use cases, process maps and exchange scenarios a set of requirements were defined in the subject areas of spatial, asset and object definitions along with various other important information & breakdown structures. These requirements are set out in the context of the required information exchange model.

It was concluded that the requirements set out during this research did not meet the current functionality of BuildingSMART openBIM standards (primarily the industry foundation classes (IFC)) and requires extension to fulfill the needs of the domain. Therefore, future work is needed to extend the IFC and related standards to meet the requirements of the ports & waterways domain set out in this paper. In response the author will continue to further detail the requirements of the ports & waterways information exchange utilizing taxonomic and ontological development techniques and begin the work of extending the IFC standard and supporting data dictionary standards to meet these requirements.

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Appendix

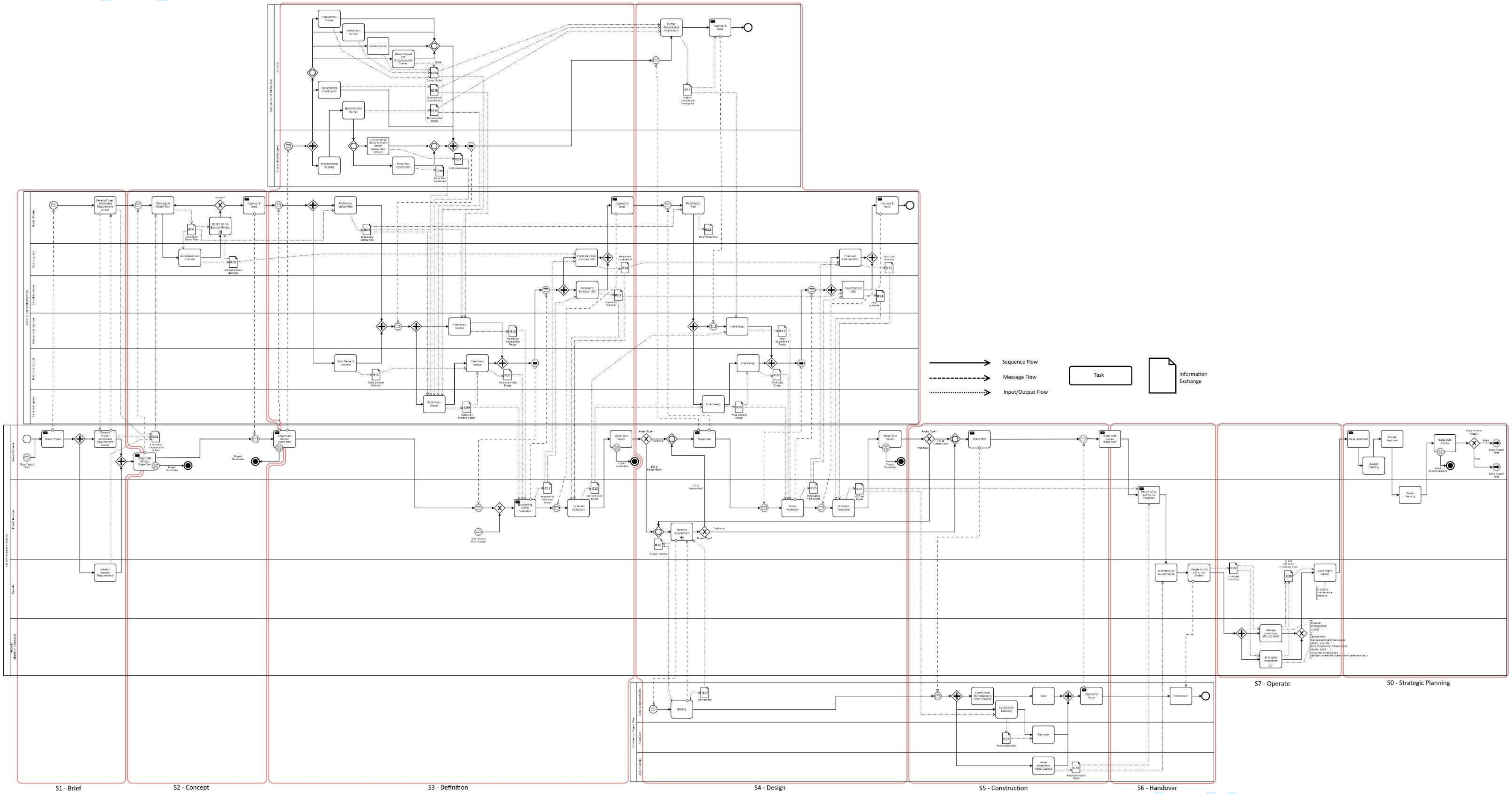

Figure 9 IFC for Ports & Waterways Detailed Process Map