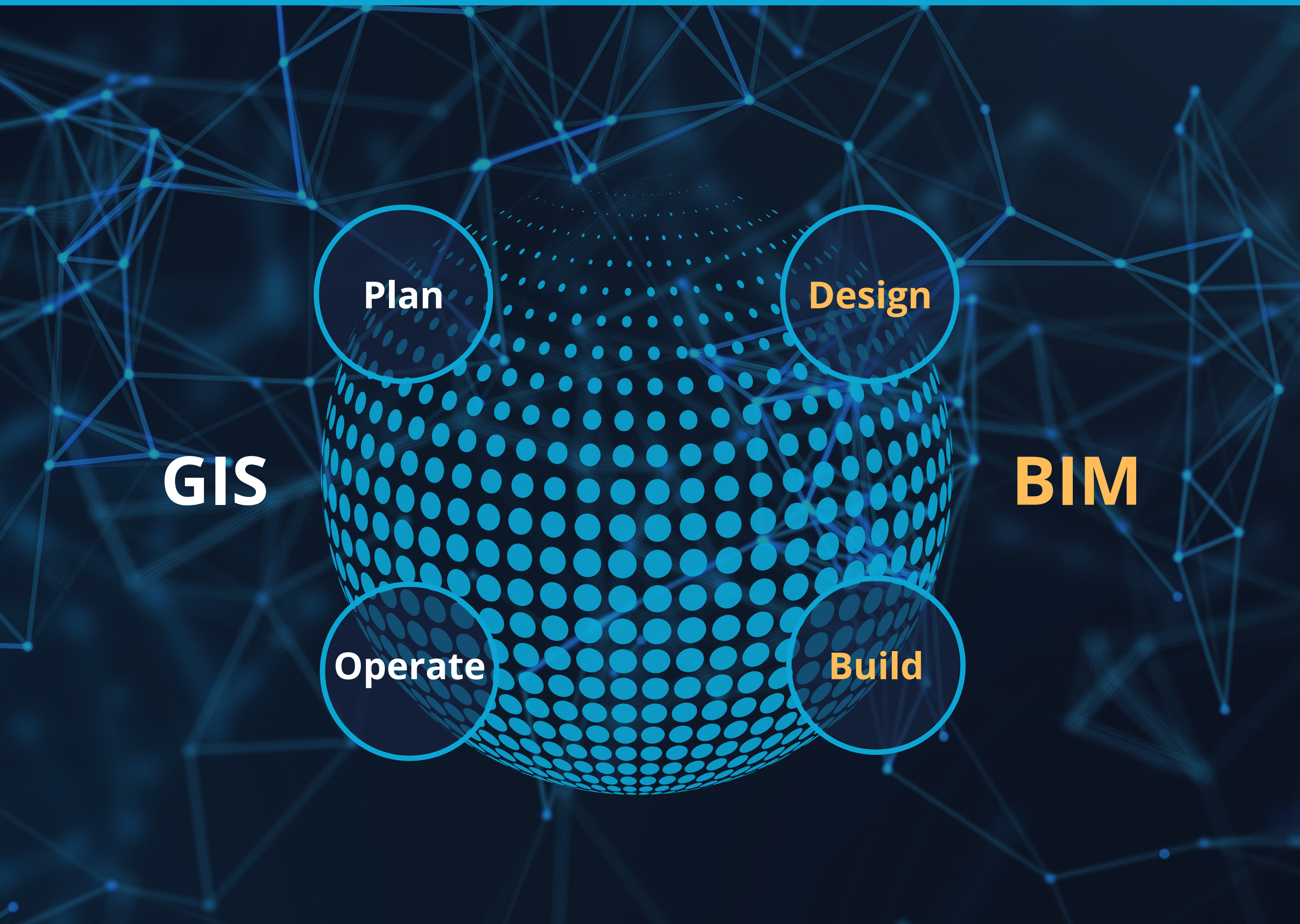
MSc thesis in Geomatics

ISO 19650 standards in Web GIS for projects information management including GIS & BIM

Khaled Alhoz

2021



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ISO 19650 standards in Web GIS for projects information management including GIS & BIM

By

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Abstract

In large and complex civil engineering projects, well-managed information enables easier and faster access to the required data when available. In the Architecture, Engineering and Construction (AEC) industry, professionals and data managers constantly seek to optimize the information management process to better collaborate in projects that include GIS & BIM integrated workflows. The publication of ISO 19650-1:2018 & ISO 19650-2:2018 (ISO 19650-1&2:2018) standards on best practices for information management, including BIM, was recognized as an opportunity to the digital organization of these processes. As a result, main BIM software vendors have started supporting ISO 19650-1&2:2018 in their platforms, and (non)-governmental organizations have started adopting them in their projects. However, the advancement in the field of GIS BIM integration and the tightly integrated workflows drew the attention towards the need for supporting ISO 19650-1&2:2018 in Web GIS for web services. I3S web service is an example of an open OGC Community standard that allows the consumption of 3D GIS data and 3D GIS data converted from 3D BIM data in Web GIS.

In this thesis, field analysis addresses the challenges and the role of the Web GIS platform in projects information management processes of the Hoogwaterbeschermingprogramma (HWBP) as a case study. Then, literature studies reviews ISO 19650-1&2:2018 in the context of the HWBP to highlight the need for a Common Data Environment (CDE) in Web GIS platform to support ISO 19650-1&2:2018. Moreover, the review tackles the CDE components specified in Part-2 of ISO 19650-1&2:2018, such as metadata allocation. Finally, this thesis discussed the implementation of the CDE components for I3S web services in ArcGIS Online as a Web GIS platform.

The novel contribution of this thesis is providing a contextual overview of ISO 19650-1&2:2018 standards in the project information management processes that include working with GIS & BIM data. Moreover, using the British national annex (BS EN ISO 19650-1&2), a flowchart was developed for the metadata allocation systems of information container workflows. Furthermore, the reference implementation discussed a variety of options to implement the metadata allocation components in Web GIS. The discussion provided a solution and PoC functionalities of the CDE components for managing I3S web services. The resulting solution on the CDE components can be utilized to configure CDE workflows and technical solutions to enable ISO 19650-1&2:2018 compliant workflows in Web GIS.

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During this thesis, my family, especially my mum, has provided me with all kinds of unconditional support despite all the stressful times I went through during this journey. Especially in the time of corona, I honestly can't find words to describe how much this all meant and will always mean to me. Finally, I would not forget about all my close friends who were always there in tough times.

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Acronyms

Introduction 1

In large and complex work such as infrastructure projects, data management is essential for collaborative production and sharing of information. The data management processes include storing, exchanging, and distributing information, including an asset's 2D/3D spatial data. Investigation and interviews have addressed the challenges faced during the information management processes in HWBP projects as a case study. The investigation has shown that many organizations have their own and different standards for data management. Therefore, while collaborating on projects, several challenges arise in the data management process leading to inefficiency and time/data loss.

The British PAS 1192 series were developed to cope with these information management challenges in projects. After the publication of the British standards PAS 1192 series, their benefits were internationally recognized for information management in projects using BIM; and organizations started requiring adopting *PAS 1192-2:2013* in their projects. As a result, the international community approached ISO and demanded elevating PAS 1192 to an international level [Shillcock, 2021]. This resulted in the publication of the *ISO 19650 series* which is international standards and principles for collaborative information management in projects.

ISO 19650 series "*Organization and digitization of information about buildings and civil engineering works, including building information modeling (BIM) — Information management using building information modeling (BIM)*" standards offer recommendations and principles for managing information over the whole life cycle of a built asset [1]. ISO 19650 standards consist of 5 parts. ISO 19650-1:2018 (Part-1) contains the main concepts and principles for information management, whereas each of the remaining parts focuses on a specific aspect of the assets' life cycle management (see figure 2.1). ISO 19650-2:2018 (Part-2) contains recommendations and requirements regarding information management in the delivery phase of assets (project-based activities). Part-3 covers requirements for information management during the operational phase of the built asset. Part-4 of the ISO 19650 series is not confirmed or published yet. Part-5, the latest part of this series, sets out requirements for a security-minded approach to information management. This thesis is concerned with Part-1 and Part-2 of ISO 19650 series, which will be referred to as ISO 19650-1&2:2018.

[1] `https://www.bsigroup.com/en-GB/iso-19650-BIM/` URL date: 2021-05-16

Both governmental and non-governmental organizations have started requiring ISO 19650-1&2:2018 standards for collaborating in projects information management. However, infrastructure projects involve the usage of BIM data in combination with GIS data which is essential for the development of such large-scale projects. The spatial context enables deeper insight for better decision making, communication, and understanding [2].

This thesis addresses infrastructure projects related to HWBP as the case study of this research (introduced in section 3.1). In these projects, the practice is that BIM and GIS data generated throughout the projects end up on the Web GIS platform. The client requires the data to be delivered in GIS readable format to be stored in Web GIS, where the asset is managed for use in further applications. Ma and Ren [2017] agree and add that having this data in (Web)-GIS platform is not only important during the project (for the designing, construction, and retrofit phase), it is used for many applications later over the whole life cycle of the asset such as maintenance work, hazard response, risk management, and energy management.

For enabling information management process compliant with ISO 19650-1&2:2018, the EN ISO 19650-1:2018 document contains the concept of a common data environment (CDE) and defines it as ”agreed source of information for any given project or asset, for collecting, managing, and disseminating each information container through a managed process.” Clause 5.1.7 in Part-2 species the components for a CDE to have in order to enable collaborative information management in projects. However, it has not been explored whether Web GIS has potentials for supporting information management workflows aligned with ISO 19650-1&2:2018 framework. Therefore, this thesis investigates the potentials of implementing these components in Web GIS as a part of the information management process.

1.1 Research objectives

The main research question for this thesis is: *How to implement a CDE in Web GIS to enable ISO 19650-1&2:2018 compliant workflows for web services?*

The aim of this thesis is to present a solution for implementing CDE components for GIS web services on the web that enables information management aligned with ISO 19650-1&2:2018 standards. Clause 5.1.7 in Part-2 list the components that a CDE shall enable. Therefore, in order to answer the main question, the following sub-questions regarding the CDE components are relevant:

[2] https://steemit.com/steemstem/@langford/gis-and-it-s-importance-to-civil-engineering URL date: 2021-05-16

- What represents an information container within the CDE on Web GIS?
- How should the information containers' states and attributes be implemented to have the advantage from the ISO 19650 compliancy?

1.2 Scientific relevance

Although Web GIS and the GIS data are essential components of working in infrastructure projects, there is hardly any research on the role of Web GIS and managing web services within the ISO 19650-1&2:2018 framework. There are also no examples of a CDE implementation or any tools/functionalities that enable applying ISO 19650-1&2:2018 standards for information management in projects that include working with GIS and BIM data as web services in Web GIS. Moreover, the interviews conducted with parties involved in the case study of this research (HWBP), such as the Afsluitdijk [3] projects, showed that there is interest in possible CDE solutions in the Web GIS platform. For example, BAM infra company is researching methods to integrate the ArcGIS platform (the Web GIS used) to projects workflows aligned with ISO 19650-1&2:2018 standards.

1.3 Scope

- This thesis regards infrastructure projects related or similar to the HWBP (the case study of this research). The information management processes regard digitally managing 3D GIS, including BIM data converted to 3D GIS data.
- The ISO 19650-1&2:2018 review (section 2.1) concerns mainly roles and activities around the CDE solution.
- The implementation of the CDE is strictly committed to discussing only the CDE components, which can be beneficial for the CDE technical solution implementation. The implementation of components regards 3D GIS and BIM data as I3S web services. Therefore, the use-case workflow illustrated in figure 5.2) is used for understanding the technical requirements of the components. It is important to note that the use-case workflow is not the same as the CDE workflow solution.
- The implementation disregards the modeling, generation, and/or acquisition of GIS or the converted BIM data. Which means that the CDE workflow and final technical solution are also disregarded.

[3] https://www.rijkswaterstaat.nl/en/about-us/gems-of-rijkswaterstaat/afsluitdijkURL date:2021-05-16

- An overview of tools for converting 3D BIM data to I3S web services will be provided, this thesis does not evaluate the conversion quality e.g., what changes apply on the structure or nature of the data converted.
- The implementation presented in chapter 5 is committed to ArcGIS Online as a Web GIS platform.

1.4 Thesis overview

Chapter 2 gives a background of ISO 19650-1&2:2018 standards. This includes elaboration on the roles, stages, and activities of Part-2 to provide insight into ISO 19650-1&2:2018 standards. Then, the CDE concept and its components are explained. Furthermore, this chapter provides a background of I3S web services and SLPK files that will represent information containers within the CDE in later chapters.

In Chapter 3, preliminary investigation reviews the ISO 19650-1&2:2018 in the context of HWBP (case study) to provide understanding of ISO 19650-1&2:2018 language around the CDE concept. Furthermore, chapter 3 highlights the need for a CDE solution in Web GIS to enable ISO 19650-1&2:2018 compliant workflows.

Chapter 4 contains an overview of the methodological approach followed in this thesis. This includes linking the results of the preliminary investigation regarding the need of CDE solution in Web GIS to the CDE components implementation scope.

Then, in chapter 5, a Web GIS platform is selected to discuss solutions on implementing the CDE components. Furthermore, PoC functionalities are implemented based on the final solution of the implementation discussion.

Chapter 6 will present the results of the implementation discussion on the CDE components in chapter 5. This includes an assessment of the covered aspect of the CDE concept in this thesis.

Chapter 7 concludes with the degree to which the research questions have been addressed. Moreover, we will elaborate on the limitations encountered during the research. Finally, points/topics to be addressed in future work will be suggested.

Background and related work

2

2.1 ISO Series

In 2018, Part-1 [BS EN ISO 19650-1 - Concepts and principles, 2018] and Part-2 [BS EN ISO 19650-2 - Delivery phase of the assets, 2018] were released. As a common approach to the collaborative management of information in projects, Part-1 and Part-2 enable teams from around the world to minimize wasteful activities and increase predictability around cost and time. Part-1, which can be adapted for projects of any scale and complexity, contains recommendations for frameworks to digitally manage information, including exchanging, organizing, sharing, and record of version history. It outlines clear principles for all parties involved throughout the entire asset life cycle, including owners, leads and non-lead designers, contractors, sub-contractors, manufacturers, investors, end-users, and public authorities. Part-2 specifies information management requirements within the context of a project's delivery phase, from design through to planning, procurement, construction, commissioning, and close-out

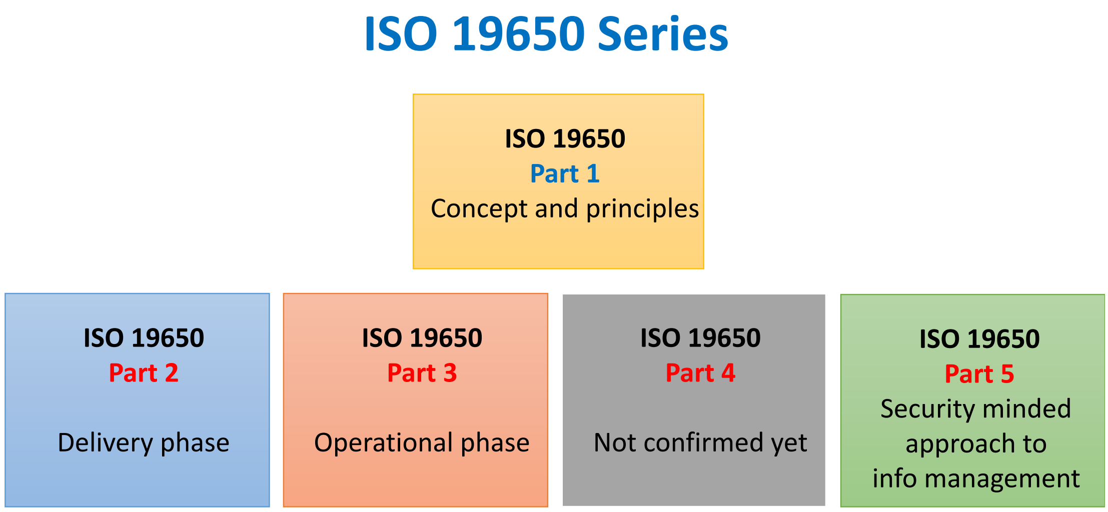


Figure 2.1: Overview of ISO 19650 Series

for built assets [1].

ISO 19650-2 clause 5 outlines eight activities (stages) per project and defines the responsibilities of each party involved in a project. Each stage (activity) contains a detailed explanation of each party's role regarding information management during the delivery phase of an asset (see 2.4). The following subsections elaborate on the roles, activities, and the CDE components as described in ISO 19650-1&2:2018 documents.

2.1.1 Roles, teams & terms

Figure 2.2 illustrates the interface between parties and teams (explained in this section) in terms of information management. The roles and terms presented in this thesis are only the ones relevant to the scope of the research. It's noted that the terms and roles explained ISO 19650-1&2:2018 are used whether or not agreements on the workflow are formal (contractual) or not.

Appointment, appointing party and appointed party The ***appointment*** is instructions agreed upon by parties involved in a project. In the case of projects relating to the HWBP, it is most likely to be a contract or a document that defines

[1] https://www.bsigroup.com/en-GB/blog/Built-Environment-Blog/iso-19650-parts-1-and-2--things-to-consider-when-implementing-bim-in-your-business/ URL date: 2021-05-16

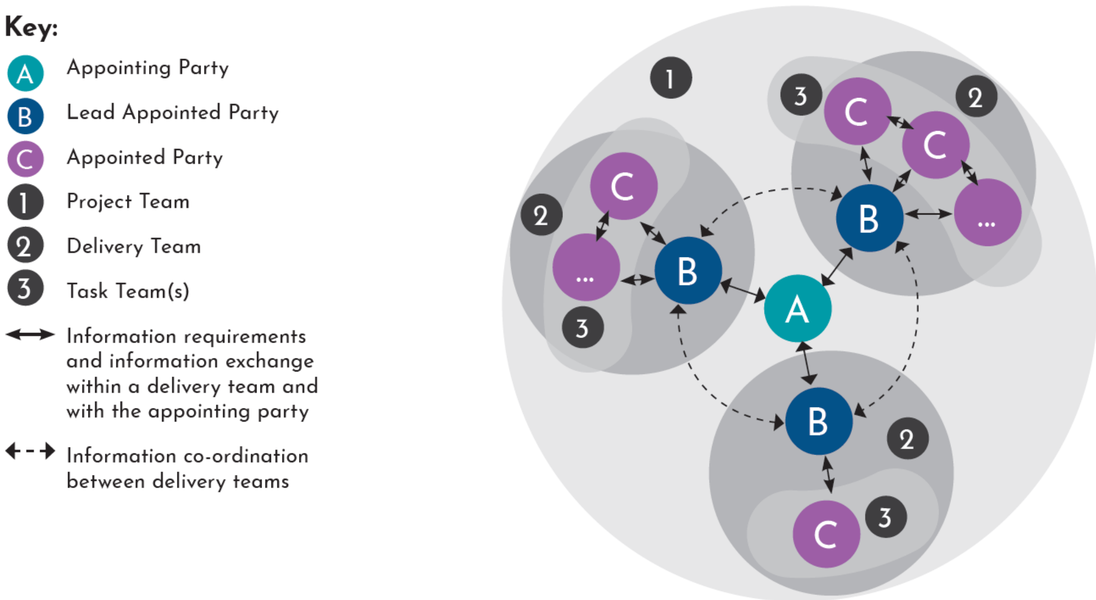
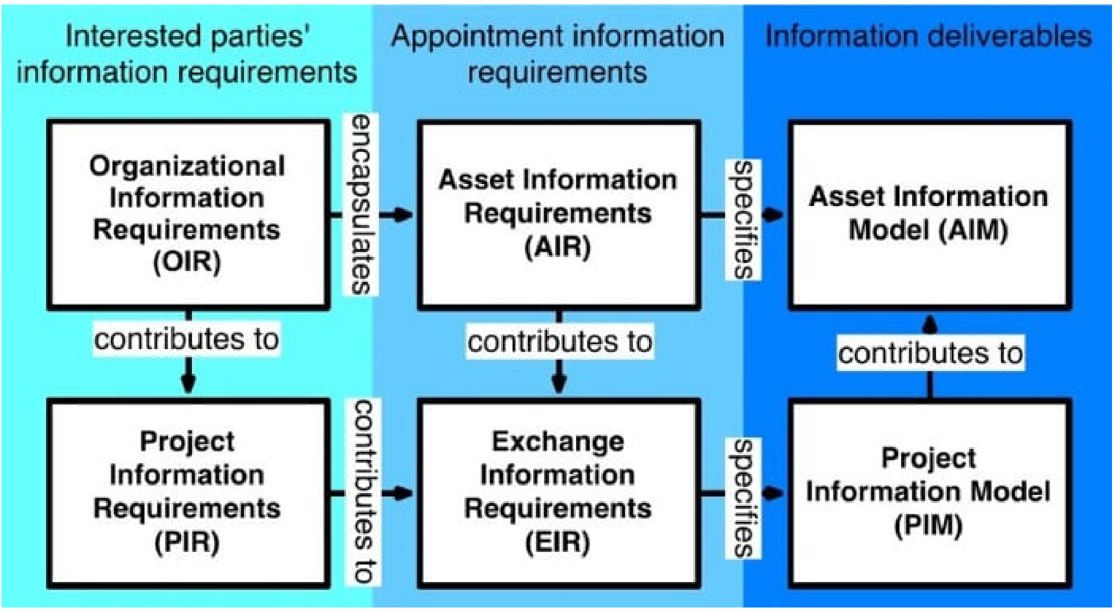


Figure 2.2: Interfaces between parties and teams in terms of information managements, [Kemp, 2021] (simplified version of ISO 19650-2 Figure 2)

the process and Information Requirements (IR).

The ***appointing party (A)*** is the receiver of information according to the IR specified in the appointment. In the context of the HWBP (more details in chapter 3), the appointing party is the client, which is mainly the Regional water authorities (waterschappen) or a party that fulfills the information management role for the client (a third party acting on their behalf) [Kemp, 2021]. The ***appointing party*** is most likely to arrange several appointments with lead appointed parties. For example, the appointing party arranges appointments for architecture, project management, and construction appointment. The appointing party is also responsible for defining the Exchange Information Requirements (EIR): for each appointment.

The ***appointed party (C)*** is the provider of information according to the IR. Each appointed party has a lead appointed party that coordinates the production and delivery of information according to an agreed delivery plan. A ***lead appointed party (B)*** can have several appointments with appointed parties (for example, if the lead appointed party is the main contractor). In the context of the case study, an appointed party is a member or a team of the (***Task Team (3)***), and that would be a (sub)-contractor, which can be a design or construction team/firm. The *project team (1)* consists of multiple *delivery teams (2)* e.g. the design delivery team and the construction delivery team 2.2.



Note: In this figure 'encapsulates' means 'provides input to', 'contributes to' means 'provides an input to' and 'specifies' means 'determines the content, structure and methodology'.

Figure 2.3: Relationships between information requirements and information models, [Kemp, 2021] (ISO 19650-1 Figure 2)

Exchange Information Requirements (EIR): The Exchange Information Requirement specifies all information required from an appointment. This information is required when making a decision at the project, asset, or organizational level. Figure 2.3 shows the hierarchy of different information requirements and information model. Therefore, setting out the Exchange Information Requirements (EIR) considers Organizational Information Requirements (OIR), Asset Information Requirements (AIR), and Project Information Requirements (PIR). EIR is prepared in such a way that allows the appointed party to respond to it through the BIM Execution Plan (BEP) (see 2.1.1).

BIM Execution Plan: A BIM Execution Plan (BEP) is the response to EIR from the delivery team. It contains an explanation of how the team will carry out the information management aspect of the appointment. This means that the BEP provides a framework that defines how appointed parties will collaborate as a delivery team. This includes what, when, and how the exchange of information is organized among task teams to develop and meet the information requirements specified in the EIR. In Part-1, the roles of BIM manager and coordinator are not described. However, information management tasks are identified for the lead appointed party (contractor) within the tender response activity (see 2.4). This allows the prospect lead appointed party to include the proposed professional title, e.g., BIM and GIS data manager [Rudden, 2019].

2.1.2 Stages & activities

The information managements process contains eight stages that are referred to as activities in clause 5 of the document ISO 19650-2 [BS EN ISO 19650-2 - Delivery phase of the assets, 2018]. These activities enable the delivery team to produce information collaboratively and minimize wasteful activities. These activities are categorized into:

- Project level (per project)
- Appointment level (per appointment, outlined in red dashed line table 2.4)

Per appointment, there are three stages Procurement, Planning, Production. In table 2.4, Kemp [2021] listed the activities with an excellent illustration of the stages and involvement (color-coded) of the parties involved (the appointing party, the lead appointed party and the appointed party).

For the scope of this research, there is no need to dive into the details of the activities. Nevertheless, they are presented to provide a context of the Part-2 stages in projects and give a sense of ISO 19650-1&2:2018 language. However, what would be good to clarify is that the CDE workflows and technical solutions are developed per appointment (or, in other words, per delivery team). For example, if a project was to have two appointments, 1- design 2- construction,

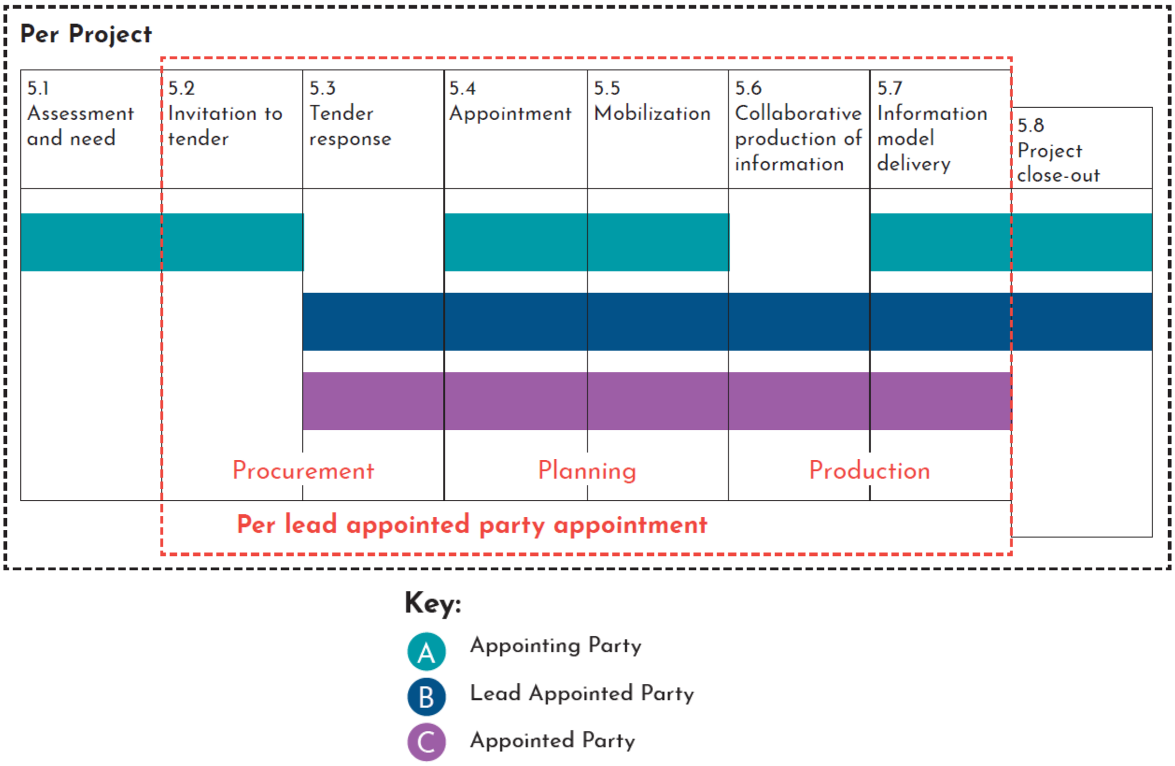


Figure 2.4: Activities and stages, table 2 of [Kemp, 2021]

there could be two CDE workflows and technical solutions, one for the design appointment and one for the construction appointment. So, the workflow and the technical solution highly depend on the complexity of the project, requirements, and type of data. Note that the information requirements, process, and the CDE workflow and technical solution are agreed upon in the *Invitation to tender* and *tender response* stages. It's also noted that making the CDE available and managing it is the responsibility of the appointing party (or a third party acting on their behalf). In some scenarios, delivery teams establish their own CDE to coordinate the production of information. However, this does not replace the CDE of the project. It actually complements it [Kemp, 2020]. In the mobilization stage, the lead appointed party configures and tests the project's CDE enabled by the appointing party. Testing the CDE solution means that you ensure the data produced by the delivery teams can be shared and published. In the case the appointed party has their own CDE solution, the lead appointed party has to address the connectivity to the project's CDE [Kemp, 2020].

2.1.3 Common data environment (CDE)

The information management process according to ISO 19650-1&2:2018 requires a CDE that facilitates the information workflow. "A CDE workflow describes the process to be used, and a CDE solution might provide the technology to support those processes". The CDE definition holds two parts, the process for collecting, managing, and disseminating information and the technological solutions that support this process [praktijkrechtlijn, 2020]. ”A CDE solution could be software, or it could be another form of tools”, and ”it must be recognized that many different technologies can be used within a single workflow” [Kemp, 2020]. Figure 2.5 shows the concept of CDE and information (containers) workflow. In this regard, [Kemp, 2020] explains the principles of the CDE workflow and the technical requirements for its implementation with examples. Moreover, Shillcock and Suchocki [2019] and Spencer [2019] have provided examples of using the Autodesk software BIM360 Docs as CDE to enable BIM workflows aligning with ISO 19650 standards.

Within the CDE, each set of information, no matter how big or small (e.g., an email, a (*.pdf) file, or geometrical data in any format), is called an information container. Using an example of 3D Civil 3D data of the Ameland dyke (more details are explained later in section 3.2), the whole model (all construction layers) of the dyke can be considered as one information container. However, depending on the project’s complexity, it may be more convenient to consider each construction layer (e.g., concrete layer or clay layer) an information container, allowing independent containers’ workflows. Another option is to have each object type in the Civil 3D file represented by an information container, e.g., Corridors (roads, highways, or railways), Pipes, Building site or

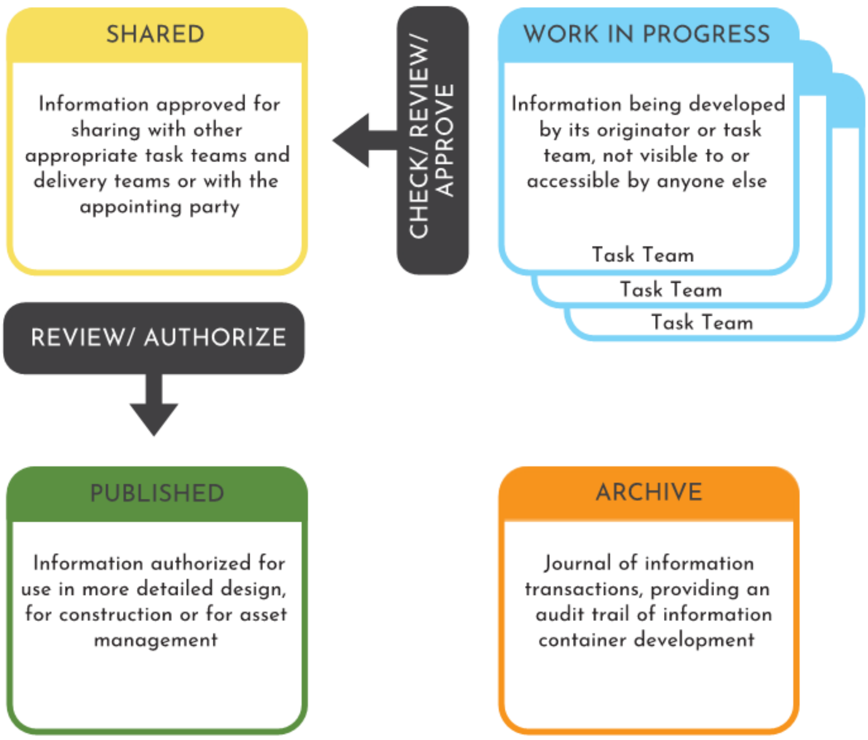


Figure 2.5: The common data environment (CDE) concept, figure 10 in BS EN ISO 19650-1 - Concepts and principles [2018]

Pressure network objects [2].

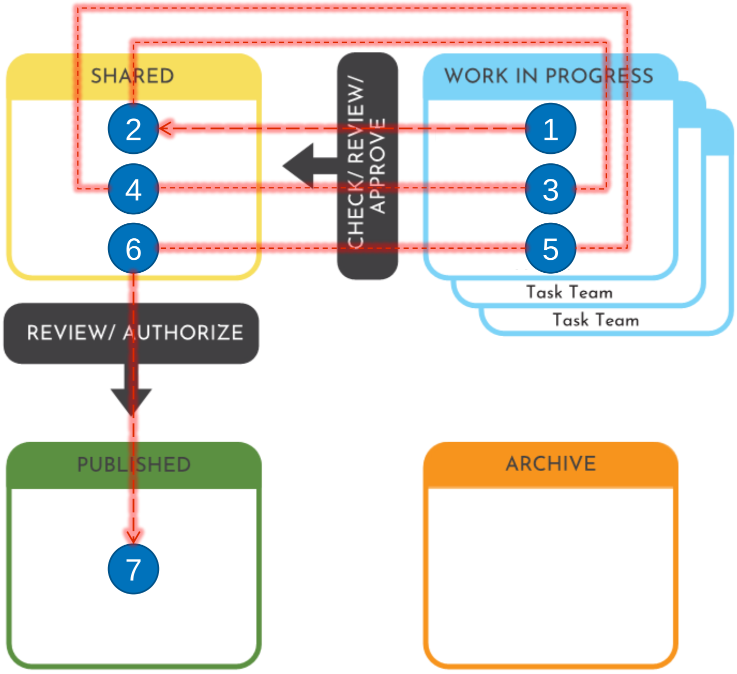
During the development of an information container, it undergoes various states (see figure below). These states are *Work in Progress (WIP)*, *Shared*, and *Published*. Actually, most information (containers) in practice go through these states during the production. For example, this research is in **WIP state** at the time of writing the content, then it will be in the **Shared state** when I share it with my supervisors for review. Finally, it ends up in the **Published state** that you can read at the moment (inspired by Kemp [2020]). Figure 2.5 illustrates a simplification of the process the containers within the CDE environment undergo. The **Archive** is supposed to contain a versioned history of this process, *for example, for this research progress, GitHub is used for version history control*. Information container workflows are managed through metadata assignment, which is a part of the CDE components. The project's CDE may have two CDE solutions or even three as the appointing party, the lead appointed party, and the appointed party all could have their own CDE. When implementing metadata assignment, attention should be paid to how metadata is transferred between the project's CDE's. Within the context of the case study (HWBP) of this research, there could be one or two CDE's for BIM data and a CDE for GIS data. The appointing party (client or their representative), as a GIS user, is then responsible for enabling the project CDE in the (Web)-GIS environment.

2.1.4 The components of the CDE solution

There are three terms related to the CDE concept that have been mentioned, which could be confusing. Therefore, before listing the CDE components, it may be helpful to explain them.

- **The CDE workflow**: the CDE workflow is planned for each appointment or phase of a project, e.g., the design phase. It explains how each type of information container is developed → checked → shared → authorized → accepted → published→ archived. A simple illustrative example of a CDE workflow is shown in figure 2.6. The workflow consists of 7 steps starting with the sketch (step 1 in the WIP state) and ending with the final design (step 7 in the Published state).
- **The CDE technical solution**: the CDE technical solution is configured for each information container workflow separately. So, it is the technology that digitally supports this information workflow within the CDE. Besides the ability to assign metadata, the solution includes the check, review, and approve functionalities and audit trail of the information containers in the archive. It also includes making comments and or visualizing/reviewing the information.

[2] Civil 3D objects URL date: 2021-08-16



The steps of the workflow: 1- Sketch/draft blueprint design work. 2- Coordination and comment. 3- Advanced blueprint design work. 4- Review and comment. 5- Final blueprint design work. 6- Final product for the project information model. 7- Published to be used in the next phase of the project.

Figure 2.6: Illustration of a simple CDE workflow of a (design)-work within the project.

- **The CDE components**: The CDE components are a list of technological capabilities (functionalities, features, or tools) that can be utilized to configure the CDE technical solution. For example, the metadata allocation components should explain where and how to assign metadata to an information container, e.g., ID, revision, and classification. Therefore, the features/tools used for the metadata allocation solution should consider the user's ability to identify the information container, its content, and its appropriate use. This means that, when searching for information containers, visibility of the metadata is required. Moreover, it should also allow performing search operations and fast filtering of the required information based on the assigned metadata's attributes.

For the CDE solution, BS EN ISO 19650-2 - Delivery phase of the assets [2018] has specified the following list of components to be addressed.

1. The ability for each information container to have an agreed upon unique ID.

2. The ability of each information container to transition between states (WIP, shared, published)

3. The ability for each information container to have the following attributes assigned (status (see table 2.1), revisions, and classification)
4. Controlled access at an information container level.
5. The recording of user details (name, date) when information container transitioning between states.

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

Table 2.1: ISO 19650-2 Table NA.1 - Status codes for information containers within a CDE [Kemp, 2020]

In their guidance, Kemp [2020] put it in a simple way and sees the first three component as metadata assigned to each information container for different purposes. For example, status codes attribute (table 2.1) makes it clear for the recipient what the content of the information container could (or could not) be used for. Furthermore, the classification attribute is used to categorize and identify the content of information container. In figure 2.7, Kemp [2020] presents and compare two CDE solutions and how metadata could be transferred between the CDEs. The last two components are straightforward and differ based on the given use case/workflow. In the reference implementation section (5.2), we will review the objectives of these components and discuss their application in Web GIS using the British national annex convention [BS EN ISO 19650-2 - Delivery phase of the assets, 2018].

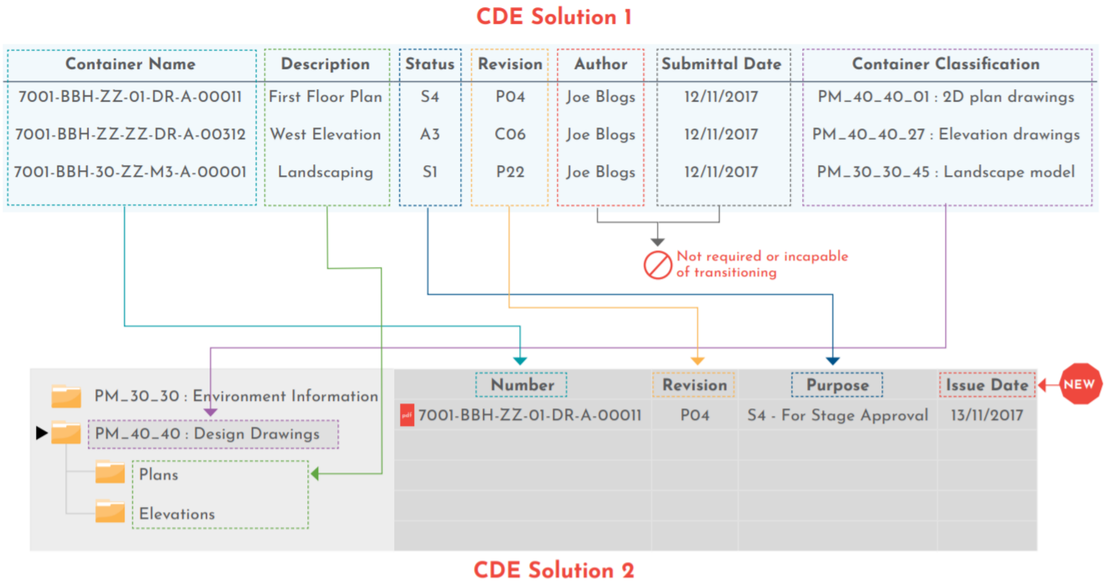


Figure 2.7: Illustration of two different CDE solutions where metadata assignment must transfer, figure 4 of [Kemp, 2020]

2.1.5 CDE checklist of actions/key points to be considered

[Kemp, 2020] defines a checklist of key points that should be tackled when facilitating a CDE workflow and technical solution. The key points are referenced from clauses in Part-2 document. For each key point, the bullets also indicates which party is responsible. The following key points should be considered when facilitating CDE solutions for each project:

Key point, responsibility and clause(s)

1 - Setting up and defining the adopted status code standards and revision system in the project's information standards. Made available by the appointing party (5.1.4) and it should be reviewed to suite the delivery requirements by the lead appointed party (5.3.2, 5.4.1).

2 - Ensuring the seamless pass of the information containers between CDEs if multiple CDE solutions owned by different organizations are being used. This include testing and ensuring that the allocated metadata can be transferred. Agreeing how information containers are transferred manually or automatically between solutions (5.5.2).

3 - Setting up classification system for the project's information standards. Made available by the appointing party (5.1.4) and it should be reviewed to suite the delivery requirements by the lead appointed party (5.3.2, 5.4.1).

4 - Implementing and documenting a clear CDE workflow for how each type of information container is developed → checked → shared → authorized → accepted → published→ archived. Associated with clause (5.5.2).

5 - Defining ID codification standards for information containers in the project's information standards. Made available by the appointing party (5.1.4) and it should be reviewed to suite the delivery requirements by the lead appointed party (5.3.2, 5.4.1).

6 - Documenting set of standard methods and procedures to outline how metadata allocation (defined in the information standard) shall be assigned to the information containers (5.5.3).

7 - Reviewing and comparing potential CDE solutions to ensure they support the agreed-upon metadata allocation (5.1.5, 5.5.2).

2.1.6 Related work

Since the release of ISO 19650-1&2:2018 in 2018, there have been some publications regarding the application of these standards for information management processes using BIM data. For example, Rudden [2019] addressed the relevance of ISO 19650-1&2:2018 to consulting engineers and the benefits of using them from BIM approach and project management perspective. Oberste-Ufer [2019] describes how ISO 19650-1&2:2018 standards will have an impact on the construction supply industry in three different ways:

- Information delivery: ISO 19650-1&2:2018 set out requirements for information management which is originally a product. Therefore, pressure on the contractor is increased to deliver the correct information at the specified requirements and time.
- Easier optimization: the set of standards is seen as an opportunity for safer, faster, and more flexible information management process overall
- Global adaptability: the clear guidelines offered by ISO 19650-1&2:2018 raise of international awareness of digitally enabled BIM information management processes and will demand parties involved to be prepared for it.

Using the British national annex of [BS EN ISO 19650-2 - Delivery phase of the assets, 2018], Kemp [2019] and Kemp [2021] present a guidance on how to implement ISO 19650-1&2:2018 standards for the information management in projects.

2.2 Web GIS & (I3S) web scene layer service

Web GIS is a web-based GIS platform that allows users to consume and serve GIS data in the form of Web services such as WFS and WMS, which are Open Geospatial Consortium (OGC) standards. For 3D data, the Indexed 3D scene layer I3S service and scene layer package (SLPK) (also referred to as scene layers) formats is an example of Web services that can be consumed and served on Web GIS. I3S is an open 3D content delivery format used to rapidly stream and distribute large volumes of 3D GIS data to mobile, web, and desktop users. I3S and SLPK are also OGC Community standards based on I3S version 1.6 of the Esri openly available specification [3]. The scene layer can be of types Points, Point cloud, 3D object, Building Scene Layer (mimics 3D BIM models), and Integrated meshes. It is possible to convert high detailed BIM data (such as (*.ifc)) to I3S scene layer (of type 3D Objects, or Building Scene Layer) and share it on the web to be used/combined with GIS data [4]. As will be indicated later in chapter 2, in some scenarios of the case study of this research, BIM data are converted to I3S scene layers and delivered in I3S format only. This thesis regards only managing this data as I3S scene layers in Web GIS. Therefore, the exact content of the I3S data is disregarded whether it is converted from BIM or not. SLPK is a single file that contains all the geometrical data of a single I3S scene layer. This means that the same data mapped to the geodatabase on the web can also be stored in one SLPK file. In the implementation chapter 5, the discussion will elaborate on how these two data formats are consumed. Moreover, it will explain how the I3S scene layer and SLPK file can best represent an information container within a CDE on the web.

2.2.1 ArcGIS Online

ArcGIS Online, a Web GIS platform supported by Esri, allows the consumption of the Web feature service (WFS) and Web map service (WMS) OGC Web services. As Esri initially developed it, ArcGIS Online also supports the OGC I3S and SLPK services. In ArcGIS Online, Web services such as SLPK can be added to the portal as items through the user interface tap (Content ⇒ My Content ⇒ New item). From ArcGIS Pro, the desktop application supported by Esri, 3D data can be directly shared as I3S Web services (scene layer) to ArcGIS Online.

[3] `http://docs.opengeospatial.org/cs/17-014r5/17-014r5.html` URL date: 2021-05-16
[4] `https://pro.arcgis.com/en/pro-app/latest/help/data/services/use-web-scene-layers.htm` URL date: 2021-08-16

Another option is to create an SLPK file in ArcGIS Pro. Then, when uploading this SLPK file to ArcGIS Online, it can be published as an I3S Web service. At the moment of conducting this research, ArcGIS Pro supports direct read of multiple BIM data formats such as (*.ifc), (*.rvt), and Civil 3D CAD data. These BIM data, as well as GIS data in 3D, can be converted to I3S Web services (scene or building scene layer) using either of the mentioned workflows [Aalbersberg, 2021].

2.2.2 QGIS Cloud

Another Web GIS platform is QGIS cloud which allows publishing maps, data, and services on the internet. In a similar concept of ArcGIS Online and ArcGIS Pro, when creating and/or editing GIS data in the desktop application QGIS, it is possible to share these data on the web using the QGIS cloud plugin [5]. QGIS cloud supports OGC web services such as WMS, WFS, and WFS-T [Pánek and Burian, 2019]. At the moment of writing this thesis, the research found no documentation on sharing 3D GIS or BIM data on QGIS cloud. Although, Orbit 3D mapping cloud, which is an independent Web GIS platform, offers a plugin[6] for QGIS, which allows viewing, sharing, and processing 3D GIS data from QGIS. Research on Orbit 3D mapping documentation has also found no examples of BIM data usage on the cloud. Furthermore, no tools have been found for supporting the conversion of 3D BIM data such as (*.ifc) to QGIS readable format. Reading answers to related questions in 2019 on the QGIS developer web page [7] confirms that, until the mentioned time, no tools support converting 3D BIM data to QGIS readable format.

2.2.3 GeoNode

GeoNode is another Web GIS platform that can be used to develop GIS applications and deploy spatial data infrastructure. GeoNode platform is designed in such a way that allows users to extend and integrate it with other platforms. It also supports OGC web services such as WMS, WFS, and WFS-T. However, in GeoNode official documentation, there is no information found for supporting the consumption of I3S service or any Web services for 3D GIS data or coming from BIM [8].

[5] https://plugins.qgis.org/plugins/qgiscloud/ URL date: 2021-07-16
[6] https://3dmapping.cloud/launching-the-qgis-plugin/ URL date: 2021-07-16
[7] http://osgeo-org.1560.x6.nabble.com/QGIS-Developer-IFC-data-in-QGIS-td5388773.html URL date: 2021-07-16
[8] https://geonode-docs.readthedocs.io/en/latest/tutorials/devel/api/ogc.html URL date: 2021-07-16

HWBP (case study) & preliminary investigation 3

This chapter provides a background of the HWBP (case study), field analysis conducted, and the outcome. Furthermore, we will review ISO 19650-1&2:2018 activities around the CDE in the context of the HWBP projects.

3.1 The HWBP (case study) & the field analysis

The Hoogwaterbeschermingprogramma (HWBP) is a prolonged program to reinforce the dykes protecting the Netherlands from water. This program is a collaboration between Rijkswaterstaat (*Dutch Ministry of Infrastructure and Water Management*) and 21 waterschappen. Reinforcing the Afsluitdijk [1] is an example of infrastructure projects and activities related to the HWBP where the Rijkswaterstaat is widening the body of the dyke and raising it by 2m. Therefore, construction companies (contractors) such as BAM are assigned for designing or construction work.

Initially, this research started with field analysis on information management in HWBP projects. The field analysis was conducted by means of an innovation sprint and interviews with stakeholders. The innovation sprint was a week-long event under the title *information management in the HWBP*. The participants were around 18 stakeholders from different roles, such as contractors, engineers, and data managers. In the innovation sprint, the stakeholders shared the challenges encountered during the information management processes in these projects. The identified challenges were summarized and documented in this research. Further details on the outcome of the innovation sprint can be found in appendix C.1.

After the innovations sprint, interviews were held with two stakeholders to investigate the role of Web GIS and GIS data in the information management processes. The interviewees were also knowledgeable of ISO 19650-1&2:2018 standards. Therefore, the questions asked in the interviews have also addressed the application of ISO 19650-1&2:2018 and the CDE solutions. For example, B, M from BAM Infra stated that BAM had been ISO 19650 certified for the design and construction. They have already implemented a CDE solution in their BIM systems and their documentation platform (SharePoint). Currently, BAM is also

[1] https://www.rijkswaterstaat.nl/en/about-us/gems-of-rijkswaterstaat/afsluitdijk URL date: 2021-05-10

researching the integration of the GIS system in their ISO 19650's CDE implementation. Therefore, they showed interest in possible solutions in the Web GIS platform.

3.2 HWBP - the information management process & Web GIS

Rijkswaterstaat (the appointing party) store and manage data in their GIS platform (KernGIS) [2] for different applications such as maintenance work and administrative purposes. Therefore, as interviews with BAM (lead-appointed party) showed, they require the final products (an asset) in a project to be delivered in a GIS readable format. This data is updated with specified attributes that are necessary for later applications. The appointed party has also stated that the size and complexity of these projects make it essential to incorporate the (Web)-GIS platform in the information management process and workflow. For example, geo-analysis should be conducted before the design phase. Moreover, two possible designs should be compared in a spatially enabled environment. Due to difficulties acquiring more details regarding the case study activities, there is no specific information workflow or the data type that this case study provides.

The scope of this research is focused on the 3D GIS or BIM data as web services on the web. Therefore, it is not essential to provide insight into the exact content of the data and its use. However, there is Civil 3D data of a dyke in Ameland in the north of the Netherlands (Lauwersmeerdijk project) received from Wetterskip. This data can be helpful to provide context and, later, to elaborate on some aspects of the CDE components and information containers representation in section 5.1.3. The Civil 3D data is one file containing construction layers of the dyke such as Beton (concrete), Klei (clay), and Fundering (foundation) layer. This data is an example of 3D BIM data processed and converted to GIS data format by the contractor. The data is utilized for geo-analysis, such as comparing two designs, calculating material costs or the asphalt (that will be recycled and used in the construction work), and/or logistics planning.

At this point of the research, regarding the case study and field analysis, the following points are of interest:

- The client (Rijkswaterstaat) as *the appointing party* (or a representative of it) in the context of ISO 19650 standards is a Web GIS user who stores and manage their data on a GIS platform called KernGIS.

[2] https://www.geomaat.nl/producten/kerngis/ URL date: 2021-05-16

- The spatial data produced and worked with is a combination of GIS and BIM data.
- GIS & BIM Data produced throughout the project end up on Web GIS platform.

The following subsections explain the outcome of preliminary investigation on the role of Web GIS and the challenges faced in HWBP projects regarding information management.

3.2.1 The role of Web GIS in the HWBP

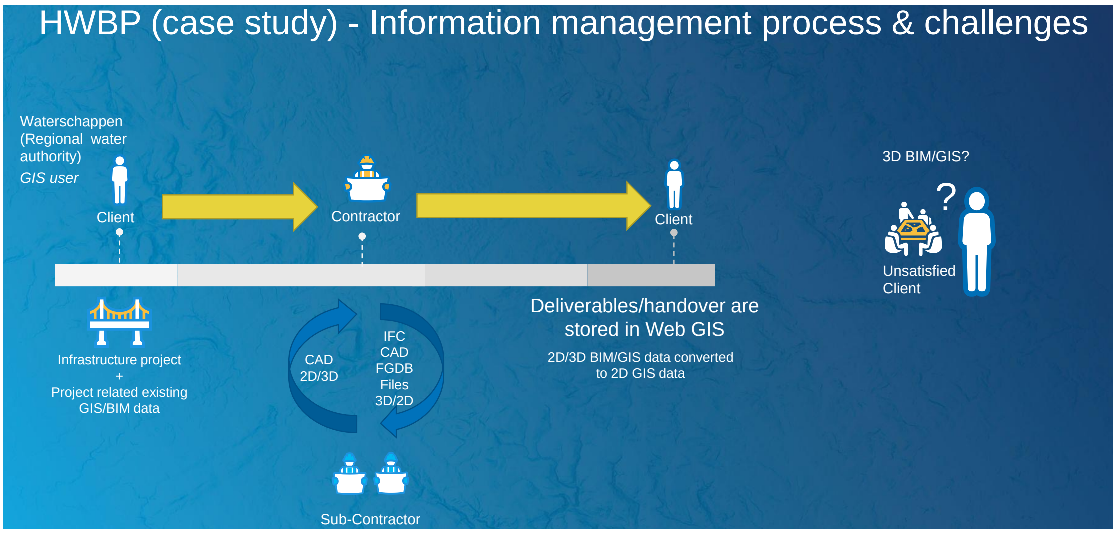
The field analysis was necessary to understand how Web GIS fits in the process of information management since no research has been found on the application of ISO 19650-1&2:2018 standards for GIS data on the web. Therefore, the goal of the interviews (available in appendix C) was to understand how Web GIS fits in the information management process. Within the context of the HWBP projects, the following was concluded:

- GIS data is an essential part of the design process (e.g. environmental analysis, site and logistics management).
- The Rijkswaterstaat stores the delivered asset (data) in a GIS Platform called KernGIS, 3.1. This data is used later for different applications, such as maintenance and administrative work during the operational phase of the asset. Hence, the BIM data produced throughout the project are mostly converted to GIS data and stored in a GIS platform.

3.2.2 The challenges of information management processes including GIS & BIM

The field analysis has also addressed the challenges in infrastructure projects regarding information management. Figure 3.1 shows a simplified illustration of the management process and information workflow in the HWBP projects. It has been mentioned in the previous subsection that The Rijkswaterstaat stores and manages their data in Web GIS. Therefore, the figure also shows how deliverables require post-processing to be converted to GIS readable format. From data collected during the innovation sprint and the interviews, this research considered only the challenges related to information management. The following list elaborates on the causes of these challenges:

1. There is a general gap between the client waterschappen and the contractor in used technology, data format and the information management standards resulting in a time loss and inefficiency in the collaboration.



The appointing party (Waterschappen) store and manage their spatial (converted BIM or GIS) data in Web GIS.

Figure 3.1: Information workflow (lower part) & management process (upper part) in HWBP projects.

2. There are no clear standards for managing (GIS & BIM) information for projects (sharing, exchanging, distributing). e.g., contractor, designers, and engineers spend much time to access reliable data available prior to the project, such as site information or older designs. Also, it is difficult to the access to most up-to-date information produced throughout the project.

3. There is no clear specification for the deliverables, e.g. attributes (semantics), formats, coordinates system (for spatial data coming from BIM), dates, etc. This results in additional post-processing work needed for the deliverable to fit the client's requirements.

4. There are no clear project requirement and/or clear project plan provided that can steer the information management process. This makes it challenging to for the appointed party (contractor) to provide products as desired by the appointing party (client).

5. Exchanging data is still mostly happening through emails or other traditional ways. And, there is no managed data environment for the projects, e.g.

   - No managed version history of the information (according to B, M from BAM Infra, this is an important aspect of ISO 19650-1&2:2018 which is requested by appointing parties).

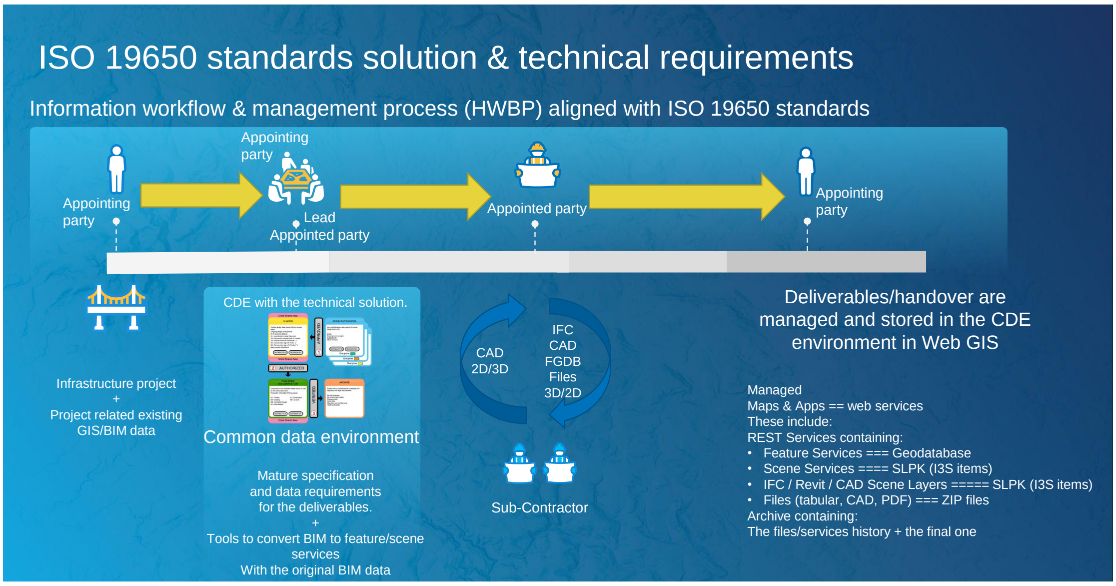
   - No clear and well-managed information workflow.

   This makes it challenging to track down the error source during the production of information.

The list of challenges shows that there is a lack of standardized collaboration in information management. It is time costly for each project to set up a plan and clarify the standards followed by each organization involved. It also costs much time to collect all necessary data related to a project prior to the project. According to N, V from Tauw, the lack of specifications for the design or the final product makes it hard to begin the work. Therefore, they, at Tauw, ask for specifications to set a work-frame and proceed. Sometimes, they don't receive any specifications, or they receive outdated specifications for 2D CAD/GIS data. That's why, in such cases, they make their own specifications to follow and to be able to work with the advanced technology. Moreover, not having a well-managed data environment makes it hard for data managers and appointing parties to keep an overall oversight of the process and data workflow. Not having an overall oversight means that, in case of mistakes in the production (e.g., design) process, the intervention happens too late.

3.3 ISO 19650 standards & the HWBP projects

Section 2.1 provided an overview of two main elements of ISO 19650-1&2:2018. These elements are the roles & activities and the CDE concept. This section



ISO 19650-1&2:2018 terms: appointing party = client (Waterschappen), (lead)-appointed party = (sub)-contractor.
The resulting data should be already in GIS readable format (also if converted from BIM) as desired by the appointing party. Moreover, it should be attributed with data required for further usage.

Figure 3.2: Illustration - the invitation to tender and tender response activities (upper part) in which each establish the CDE workflow (including the technical solution) and information requirements (lower part)

explains how these two elements relate to the list of challenges identified in the previous section (3.2.2). Figure 3.2, in the context of the HWBP projects, show a simplified illustration of the information workflow around the CDE and the management activities (invitation to tender and tender response) of ISO 19650-1&2:2018.

As explained in section 2.1.1, each party involved in projects aligned with ISO 19650-1&2:2018 standards has a defined role regarding the information management process. Throughout the 8 activities (see figure 2.4) , Part-2 specifies the responsibilities and duties assigned to each role in an ISO 19650-1&2:2018 compliant project. As the main goal is to understand the requirements of a CDE solution, the review was focused on activities and responsibilities regarding the CDE workflow and technical solution.

With respect to challenges 1, 3, and 4 mentioned in 3.2.2, the availability of well-defined roles and activities in projects leads to better-defined responsibilities for the waterschappen (client or appointing party) and contractor (appointed and lead appointed parties) throughout the project. Having the roles defined with specified activities and responsibilities adds pressure on the involved parties to meet their responsibilities. E.g., the appointing party (waterschappen) is required to define the specification and the requirements of the data to be delivered. The (lead) appointed party is pressured to meet these specifications and requirements. Examples of defined responsibilities, which were mentioned in section 2.1.2, are:

- The project's CDE is established by the appointing party or a third party acting on their behalf.
- The appointing party ensures that mature specification and requirements of the data are defined prior to the project.
- The lead appointed party configures and tests the project's CDE enabled by the appointing party.
- The lead appointed party ensures the CDE solution of the appointed party, in case they have their own, is connected to the project's CDE.

With respect to challenges 2 and 3 in 3.2.2, the ISO 19650-1&2:2018 specify requirements and standards for information management and the exchange of this information. ISO 19650-1&2:2018 set up requirements for the information management workflows. They also species how processes of sharing and exchanging should be enabled. For example, the appointed party with their lead appointed party check, review, and approve a design at the gateway when an information container is transitioned from WIP to Shared state. The check and review are done with respect to the project requirement available before the invitation-to-tender phase of a project. Furthermore, Part-2 outlines how the technological solution, in the form of a CDE environment, should serve and enable these digital processes.

With respect to challenge 5 in 3.2.2, the ISO 19650-1&2:2018 specifies requirements and standards for CDE workflow and the technical solution that grants controlled and reliable access to most up-to-date information; Part-2 outlines the technical components that a CDE should have in order to enable controlled information workflows. One component explains that each party involved in the project has access privileges to the CDE based on their role and responsibilities. For example, a designer of the task team can make changes to the information container (e.g., a design) only in the WIP state, whereas lead appointed parties can only add comments and feedback to it in both WIP and Shared information states. Furthermore, the CDE allows the appointing party (and the lead appointed party) to have an oversight of the information being produced throughout the project. If the information production deviates from the requirements, the oversight over the in-production information allows the appointing party to intervene in time. Therefore, the appointing party can prevent wasting time that the appointed party would spend on worthless work. Moreover, the metadata specifications, such as the status codes, the revision, and container classification systems, allow fast and reliable filtering of the data according to its need. For example, a data manager can perform a search operation on data classified as **architecture site-plan**, suitable for review and comment ***status code S3*** (see table 2.1) and from ***primary revision P.03*** (see figure 5.3).

The controlled information management process and controlled CDE lead to a generally optimized process. Through metadata systems, the CDE enable easier and faster access to reliable information, which saves time. Moreover, ISO 19650-1&2:2018 ensures that the (exchange) information requirements are set with respect to asset information requirements. Hence, the final products (information containers) should be delivered in the desired format and with the required attributes to be directly utilizable for the future application of the asset. Therefore, no post-processing or conversion of the deliverable is required, saving time and minimizing data loss.

Methodology 4

Figure 4.1 shows the general flowchart of the methodology. First, chapter 3 has employed a combination of literature study and field analysis for investigating ISO 19650-1&2:2018 standards in the context of HWBP project information management as a case study. Then, this research will choose a Web GIS platform to discuss and test the implementation of CDE components in chapter 5. The paragraphs below explain the steps in more detail.

4.1 Information management workflow & the role of Web GIS - HWBP (case study)

Infrastructure projects related to the HWBP were used as a case study in this research. Field analysis, by means of interviews and desk studies (see section 3.1), was conducted on the information management workflows of the HWBP to: first, identify the role of Web GIS and GIS data in infrastructure projects. Recognizing the role of Web GIS in current practice is essential to understand what components Web GIS shall serve in projects aligned with ISO 19650-1&2:2018 standards. Second, explore information management challenges in projects information management that include working with GIS & BIM data. This step is necessary in order to understand how ISO 19650-1&2:2018 standards apply in practice and fit in the identified challenges of the current practice. The investigation was done in the context of the Afsluitdijk projects as an example of HWBP projects (see section 3.1). More information and the discussion on the outcome of the field analysis are to find in section 3.2.

4.2 Literature review of ISO 19650 standards

Besides researching the role of Web GIS and its importance in projects and asset's information managements, the literature review, in the context of HWBP, addresses ISO 19650-1&2:2018 standards for information management workflow during the delivery phase of an asset (in project-based workflow). For doing so, ISO 19650-1&2:2018 documents and guides on how to implement them such as [Kemp, 2019], [Kemp, 2021], and [praktijkrechtlijn, 2020] are used. This step is carried out in order to give context of ISO 19650-1&2:2018 standards and getting a sense of its language including the roles (figure 2.2) and the 8 phases/activities (illustrated in table 2.4). The review of the eight activities focused on the parts related to the CDE components and technical solution (addressed in section 2.1.2) as it is helpful for the next step of this research. Moreover, the brief overview of the eight activities aims at recognizing the benefits of applying ISO 19650-1&2:2018 standards and how these standards can help overcome the challenges identified in section 3.2.1. The findings on the role of Web GIS and information management challenges are used to develop a scenario (ISO 19650 solution) for information managements workflows that comply with ISO 19650-1&2:2018 standards in order to overcome those challenges (see figure 3.2 for illustration). Section 3.3 elaborates on how ISO 19650-1&2:2018 framework

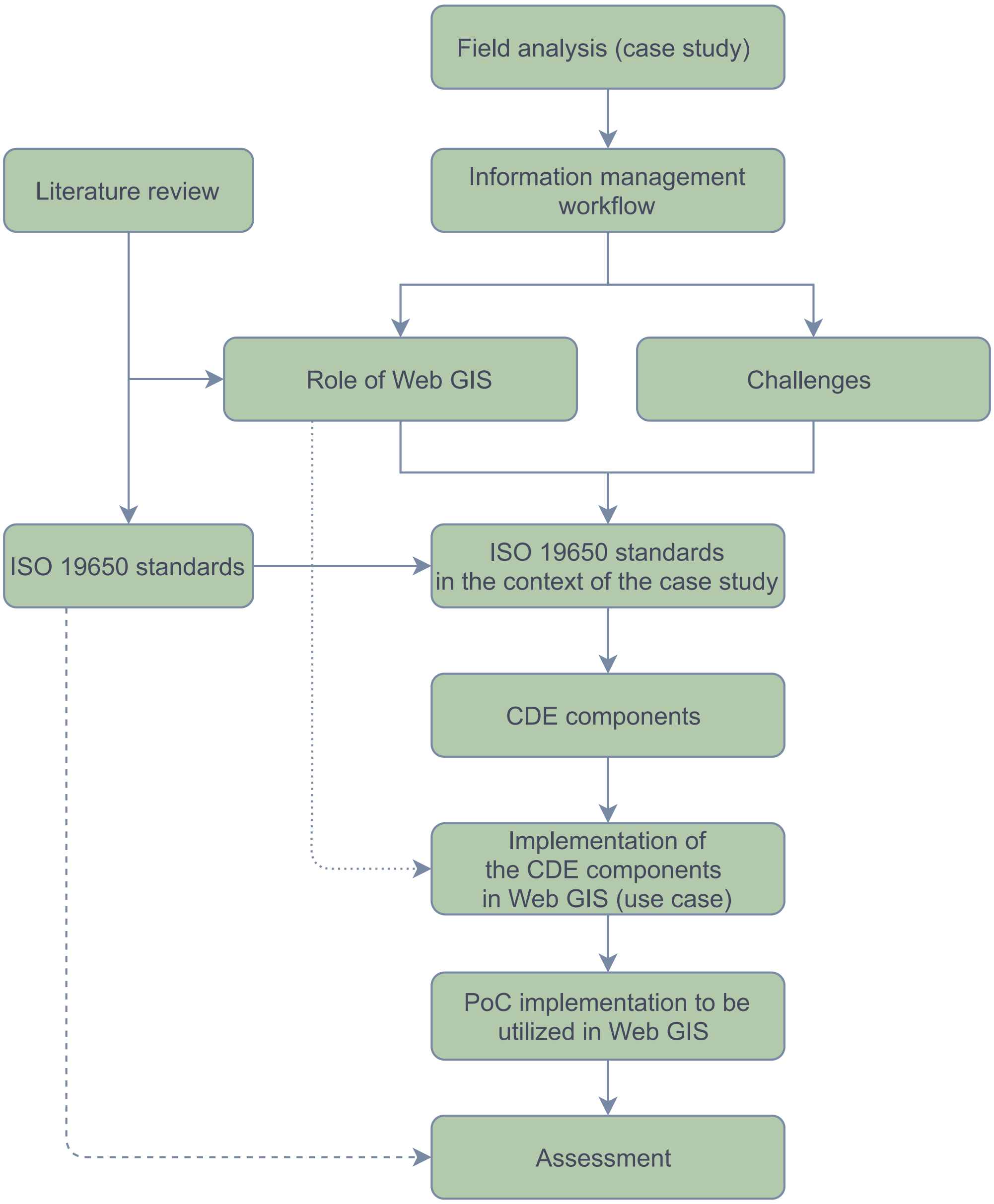


Figure 4.1: Methodology flowchart

would help in overcoming the identified challenges.

4.3 The CDE components, workflow and technical solution in Web GIS

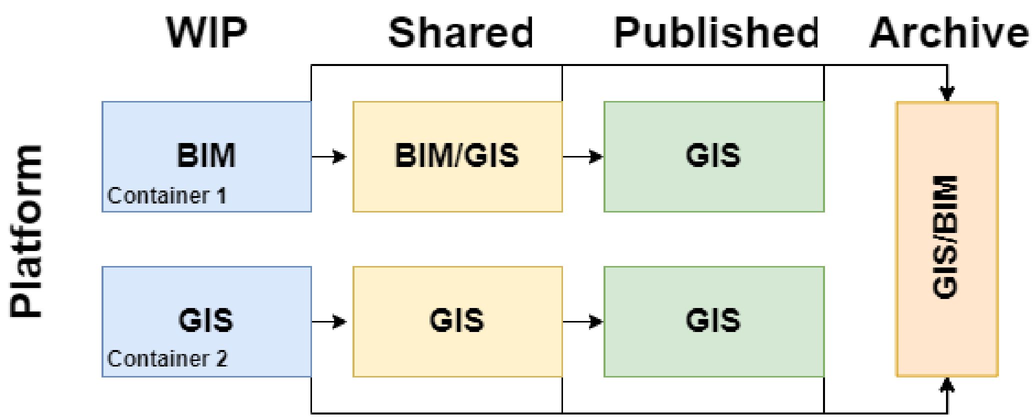
Section 2.1.4 has explained three terms regarding the CDE concept that may be confusing. It may be helpful to review these terms before reading this section to follow the explanation better. According to Part-2, projects' information workflows are enabled in a CDE. Therefore, besides the research on the activities related to the CDE solution, the study presents a detailed review of the CDE workflow and technical solution. The CDE technical solution requires a list of components which are specified in Part-2 clause 5.1.7. Section 2.1.3 elaborates on CDE's components as explained by Kemp [2020] using the British national annex [BS EN ISO 19650-2 - Delivery phase of the assets, 2018]. praktijkrechtlijn [2020] is also used for better understanding of ISO 19650-1&2:2018 standards. The CDE workflow and technical solution include different types of data formats (files such as *.pdf, word, or other types of data in a database). However, the focus of the investigation is solely on the 3D GIS & BIM spatial data as I3S web services in the Web GIS platform (see figure 4.2).

Taking the Afsluitdijk projects mentioned as an example of HWBP projects (3.1), BIM data are generated by different appointed parties (construction companies) in different formats. For example, the pumping station (for pumping water from one side to another of dyke) is designed using (*.rvt) format, whereas the dyke's body is designed using (*.dwg) format (Civil 3D). As mentioned in section 2.2, similar to (*.ifc) BIM data, it is possible to convert (*.rvt) or (*.dwg) in 3D to I3S web service (scene layer). The conversion of BIM data to I3S web services is essential as the appointing party (client) requires them in GIS readable format to be utilized in further application. Furthermore, during the projects, these BIM/CAD data converted to I3S scene layers can be combined with GIS data (such as I3S mesh or tabular) in the Web GIS portal to conduct analysis and/or to compare multiple designs. For example, Wetterskip company converts 3D objects (construction layers of the dyke) in Civil 3D to GIS readable format using FME tools extension (data integration tools in ArcGIS Pro). This converted CAD data can be deployed to simulate how the waves break over the dyke edges in the new situation. They also use the GIS platform for logistics planning, such as selecting the better side of the dyke to have the materials delivered for the construction work.

The scope of this thesis is not concerned with the conversion process, or the actual data/attribute converted. Instead, the implementation focuses the CDE components regarding these data as I3S web services in Web GIS (see later section 4.3.1). In the context of the CDE solution, the whole model (as a scene layer) can be one information container. Another option is to break down the BIM/CAD model into discipline-based models. Then, they can be converted to discipline-based scene layers as information containers (see section 5.1.3 for more details).

As mentioned in section 2.1.3, there could be one, two or even three CDE solutions. Moreover, it was mentioned that attention should be paid to how to transfer information containers, with their (desired) metadata 2.1.4. For BIM data (container 1 in figure 4.2), this is the case as there should be at least two CDE solutions, one in the GIS platform and one in the BIM platform. Regardless of who facilitates the CDEs (appointing party or appointed party), implementing the CDE components for container 1 requires integration between different platforms, e.g., using API's or transferring the data manually. Both approaches are not within the scope of this research. Instead, the focus is on the (Web)-GIS side of the workflow. Therefore, in chapter 5, this thesis chooses a Web GIS platform to study the application of the CDE components for managing I3S web services.

However, the work will present an overview of 3D BIM data formats that can be converted to I3S web services in the chosen Web GIS platform. Furthermore,



Given that the appointing party requires the final product in GIS readable format, two possible workflows can be projected on the CDE concept:
container 1: product designed in BIM software, converted to GIS data, and pushed to (Web)GIS platform
container 2: product designed in GIS software and pushed to (Web)GIS platform

Figure 4.2: GIS & BIM information containers workflow in an infrastructure project - transitioning between platforms and the CDE states (projected on the CDE concept illustrated in figure 2.5)

the overview provides a workflow available and the tools necessary for converting BIM data in (*.ifc) format to I3S Web services, e.g., (BIM ⇒ File GDB ⇒ SLPK ⇒ I3S, see section 5.1).

4.3.1 Implementation of the CDE components

Whether the data is coming from BIM or (Web)-GIS platform, it is required to have a CDE technical solution in Web GIS to enable ISO 19650-1&2:2018 compliant workflows for both GIS data as well as BIM data converted to GIS data and pushed to Web GIS. In section 5.2, this thesis addresses the implementation details of the CDE components mentioned in section 2.1.3 in Web GIS platforms. Therefore, a more detailed overview of the components will be presented, and the possibility of its application will be discussed. Implementing the CDE components according to ISO 19650-1&2:2018 standards differs not only per platform, data type, and format but also by what the protocols of the workflows are. Therefore, the discussion explores implementation possibilities in the chosen Web GIS platform according to the British national annex [BS EN ISO 19650-2 - Delivery phase of the assets, 2018] protocols and conventions. The documentation and resources available of the chosen Web GIS will be employed for addressing the CDE components. Also, examples of CDE's solutions in other platforms are compared. This being said, the implementation discussion should enable fully configuring CDE (general)-workflow and technical solution on the Web GIS platform (container 2 in figure 4.2). However, for container 1, the CDE implementation could be utilized to configure the technical solution only from the Web GIS side of the workflow. Therefore, the discussion suggests possible solutions for implementing the CDE components which could help users implement and enable ISO 19650-1&2:2018 standards in Web GIS for similar workflow. The points tackled in the implementation chapter are:

1. Metadata assignment including *information container ID, states*, and *information container attributes (status, revision and classification)*.
2. Controlled access at an information container level.
3. Record of the information containers' history.

The components are addressed using a general use case workflow for uploading (converted)-3D BIM/GIS data as I3S web services to Web GIS. Note that the use case workflow is not the same as the CDE workflow solution. However, the use case workflow is necessary to discuss the possible implementation of some of the CDE components, such as the audit trail of the information container. Figure 5.2 in chapter 5 illustrates an example of such workflows. Furthermore, a proof of concept is implemented using Rest API in Python scripting language as described in the implementation chapter (5). The functions aim to automate steps of the workflow, such as metadata allocation. Figure 4.3 was developed to illustrate the technical capabilities for an information container workflow. The implemented function(s) should be able to:

- Allow transitioning between states (WIP, Shared, and Published)

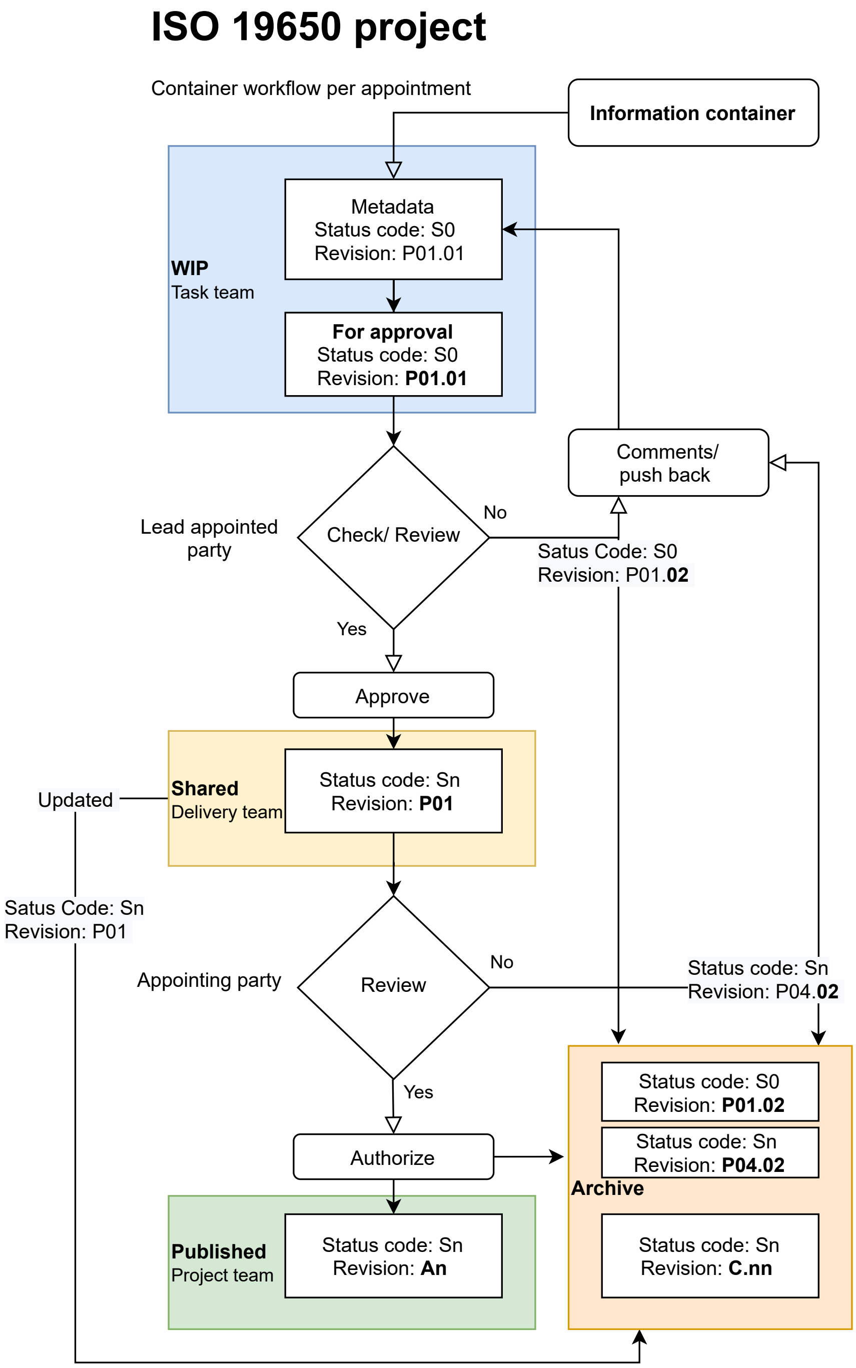


Figure 4.3: Flowchart: information container workflow within a CDE according to ISO 19650-1&2:2018 (British national annex conventions), inspired by [SymetriUK, 2020]

- Update revision, status attributes accordingly
- Allow check/review/approve of an information container, and
- Register a record of the user details and dates when any of the previous action is taken.

These functions could be utilized in Web based application as user interface or directly in the chosen Web GIS platform.

4.3.2 Assessment

In section 2.1.5, it was explained that a checklist of key points/requirements should be considered when setting up the CDE workflow and technical solution. The key points of this checklist will be used to assess the implementation of the CDE components in chapter 5.

Implementation 5

This chapter discusses the implementation of CDE components in the context of web services in Web GIS with proof of concept implementation. The components are implemented for I3S web services (scene layers) as information containers, whether they are in GIS format or converted from BIM data.

The comparison on the Web GIS platforms in section 2.2 has shown that ArcGIS Pro allows conversion of 3D BIM data to I3S (and SLPK) web services. I3S web services and SLPK are compatible with ArcGIS Online. Moreover, Esri Nederland, the hosting company of this research, provided ISO 19650-1&2:2018 documents, the necessary tools, and access to the ArcGIS platform (Esri's Web GIS platform). Therefore, the discussion and proof of concept implementation are carried out in/for ArcGIS Online as a Web GIS platform.

Before tackling the components, we will elaborate on the 3D data types supported by I3S web services in the ArcGIS Platform in section 5.1.1. Then, considering its relevance, section 5.1.2 reviews and lists the 3D BIM formats that can be converted to I3S web services as information containers.

5.1 BIM and GIS data to ArcGIS Online as I3S web services

For BIM data (container 1 in figure 4.2), as mentioned in the methodology chapter (4), it is possible to convert 3D data in a (*.ifc) file to I3S web service(s). The scope of the thesis does not concern the exact content of data during the conversion process of BIM data (container 1 in figure 4.2). The implementation focuses on managing the I3S web services on the web, whether it is GIS or converted from BIM data. However, section 5.1.2 gives an overview of the BIM data supported in ArcGIS Pro with an example of workflow to convert a 3D (*.IFC) file to I3S web services. Furthermore, section 5.1.3 discusses how it is desired to have (converted) 3D CAD data of a dyke as I3S web service on the web according to ISO 19650-1&2:2018.

5.1.1 I3S and SLPK in ArcGIS Online

SLPK is a single file that contains all the geometrical data that could be published to ArcGIS Online. SLPK can be simply uploaded to the portal and published using the publish tool available. Publishing an SLPK file in the portal creates an I3S item in the portal. After the publishing process, the SLPK is retained as a downloadable file in the portal. This means a copy of data of the I3S item is available and maintained in the SLPK and could be (re)-published. SLPK and I3S web services support different types of data in 3D. The following is a list of all types with the geoprocessing tool available in ArcGIS Pro to create the corresponding SLPK file of these data [1]:

- 3D object scene layers (mainly used for BIM and GIS data) **Create 3D Object Scene Layer Package** tool
- Building scene layers (mainly used for BIM data) **Create Building Scene Layer Package** tool
- Integrated mesh scene layer **Create Integrated Mesh Scene Layer Package** tool
- Point cloud scene layer **Create Point Cloud Scene Layer Package** tool
- Point Scene Layer **Create Point Scene Layer** tool

5.1.2 3D BIM data to I3S in ArcGIS Pro

Direct-read (direct-conversion) of several 3D BIM/CAD data is supported in ArcGIS Pro. The following BIM/CAD data formats can be directly read (converted to 3D feature classes in File GDB) without the need for any additional tools.

1. International Foundation Class (*.IFC) data in 3D can be converted to an I3S scene layer (a new capability that was added while this research was conducted).
2. Autodesk Revit data (*.rvt) in 3D (can be converted to an (I3S) scene layer) [Aalbersberg, 2021].
3. Autodesk Civil 3D and CAD data (*.dwg) in 2D/3D (3D data can be converted to an I3S scene layer) [2].

[1] https://pro.arcgis.com/en/pro-app/latest/help/data/services/use-web-scene-layers.htm URL date: 2021-07-16
[2] https://pro.arcgis.com/en/pro-app/latest/help/data/cad/supported-civil3d-objects.htm Url date: 2021-07-16

When loading a file in one of these formats to ArcGIS pro, it is read (converted) as feature classes layers in a File GDB (*.gdb). The 3D data are converted and stored in a feature class called multipatches. A *multipatch feature class* is a GIS 3D object represented in patches that store texture, color, transparency, and geometric information representing parts of a feature. Rahman and Maulud [2019] refer to multipatch geometry as an integrated data format and present three methods for converting (*.IFC)/(*.rvt) data to multipatch. The 3D multipatch layers can be grouped together or separately published as an I3S scene layer service to the ArcGIS Platform. For doing so, there are two (use cases) methods available [3]:

- **Option 1: Publish from an ArcGIS Pro scene**
  ArcGIS Pro, from File GDB using *share as web layer* tool ⇒ Scene layer (I3S) service with associated feature service.
- **Option 2: Publish from a scene layer package**
  ArcGIS Pro, from File GDB using *create-3DSceneLayerPackage* tool ⇒ SLPK file ⇒ upload to WebGIS/publish ⇒ Scene layer - I3S service.

So, the full workflow to convert an (*.IFC) file to I3S Web services in ArcGIS Pro is:

1. **Input**: (*.IFC) file - **tool:** *quick import data interoperability extension required*) ⇒ feature classes (3D objects) in File GDB
2. **input**: feature classes (3D objects) in File GDB - **tool:** *Add 3D Formats to Multipatch* geoprocessing tool ⇒ 3D object feature class
3. **input** 3D object feature class - **tool:** *Create 3D Object Scene Layer Package* tool (Data Management) ⇒ SLPK file which could be uploaded to Web GIS and Published as an I3S Web Service.

5.1.3 Civil 3D data to I3S as information containers

Having presented the conversion of 3D BIM data overview in ArcGIS Pro, this paragraph discusses the civil 3D data provided for testing (see section 3.1). As mentioned in section 2.1.3, there should be at least two CDE environments, one in the GIS platform and one in the BIM platform. It was also mentioned that it is desirable to have each information container has one semantic data set. So, the ideal situation for transferring the Civil 3D data to the GIS platform is to mimic the structure of the data in the BIM platform. Therefore, ISO 19650-1&2:2018 recommends uploading each discipline/layer (e.g., concrete, clay, road, or pavement) as one I3S scene layer (called Item in the ArcGIS Platform). Figure B.1b is an illustration of one layer (concrete) of the Civil 3D converted to a single I3S scene layer. As reference data, all layers of the model may be converted to a single I3S scene layer (see figure B.1a). Note that scene layers are illustrative

[3] https://doc.arcgis.com/en/arcgis-online/manage-data/publish-scenes.htm URL date: 2021-05-16

examples. However, the same applies to all information containers (items) regardless of their type or format. It is also noted that each use case may state different circumstances. This affects the decision on what an information container would be.

5.2 CDE and information containers in ArcGIS Online

Implementing the CDE components listed in section 2.1.4 to enable the workflow differs per platform and per data type. For example, an option to be used

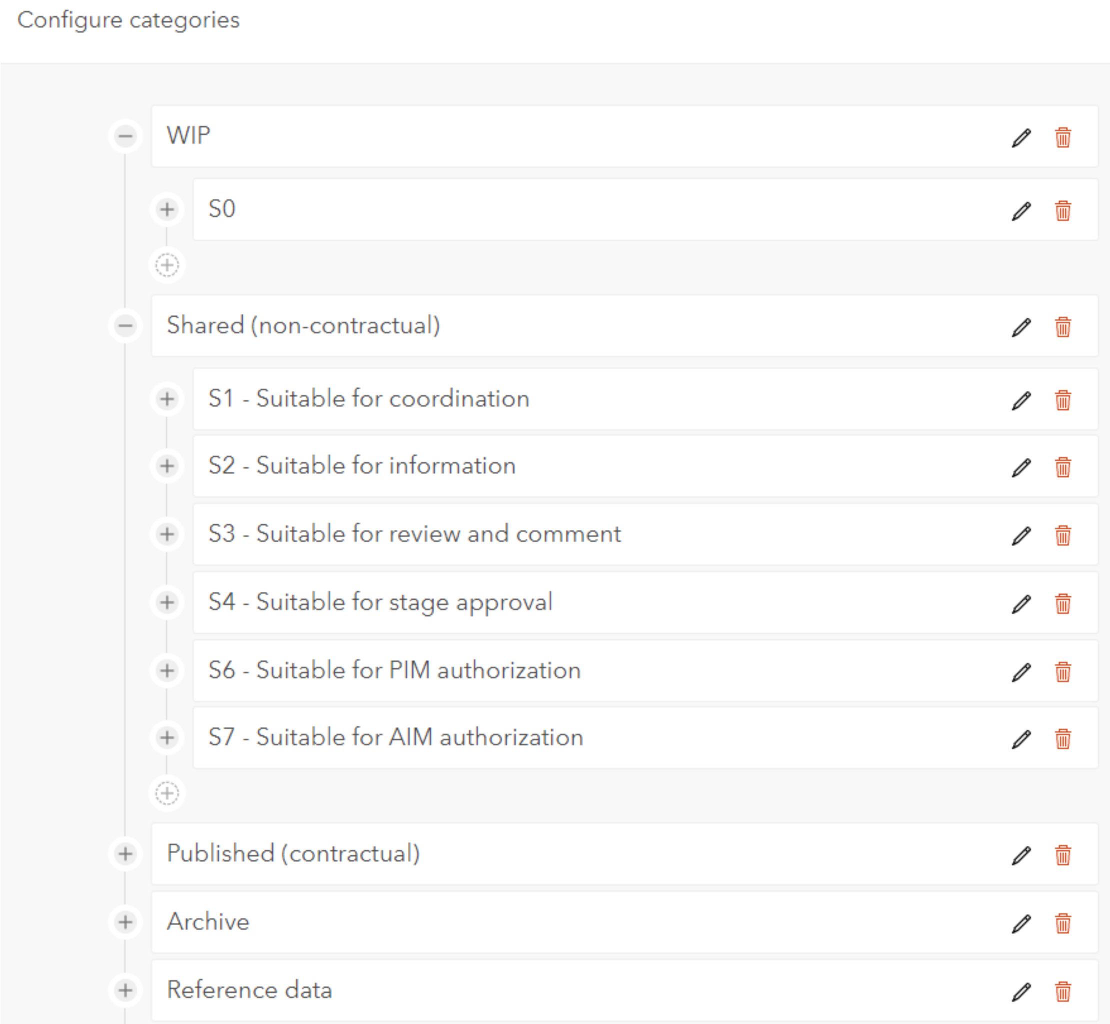


Figure 5.1: Example of a group (sub)-categories configured to enable filtering content according to the CDE states and status codes aligned with ISO 19650-1&2:2018

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is by simply deploying metadata fields to assign states (WIP, Shared, and Published) and attributes (status, revisions, and classification) to an information container. Another option, which is presented by Shillcock and Suchocki [2019] (Author of Part-2) and Spencer [2019] is by creating folders that represent *WIP, shared, published, archive* for the states; and the files within them are assigned attributes for *status, revisions, and classification*.

In ArcGIS Online, the web service feature *Group* is a collection of items (content) usually related to a specific area of interest. Group feature allows controlling who can find and join the Group. Moreover, it allows specifying who can share and contribute content to it. Furthermore, the items in a group can be organized in hierarchical categories to make it easier for the user to filter out the required items. Figure 5.1 shows an example of a group (sub)-categories configured to enable filtering out content according to the CDE states and status codes aligned with ISO 19650-1&2:2018. I3S scene layers are examples of items (content) in ArcGIS Online portals that can be managed using these categories. Groups feature can be used to allow members to work closely together on projects. Administrators can also create groups that allow members of the Group to update items shared with that group [4]. Furthermore, ArcGIS Online allows searching for content in Groups you are a member of in the My Groups tab. The user can also search for a specific group and then search within this Group [5].

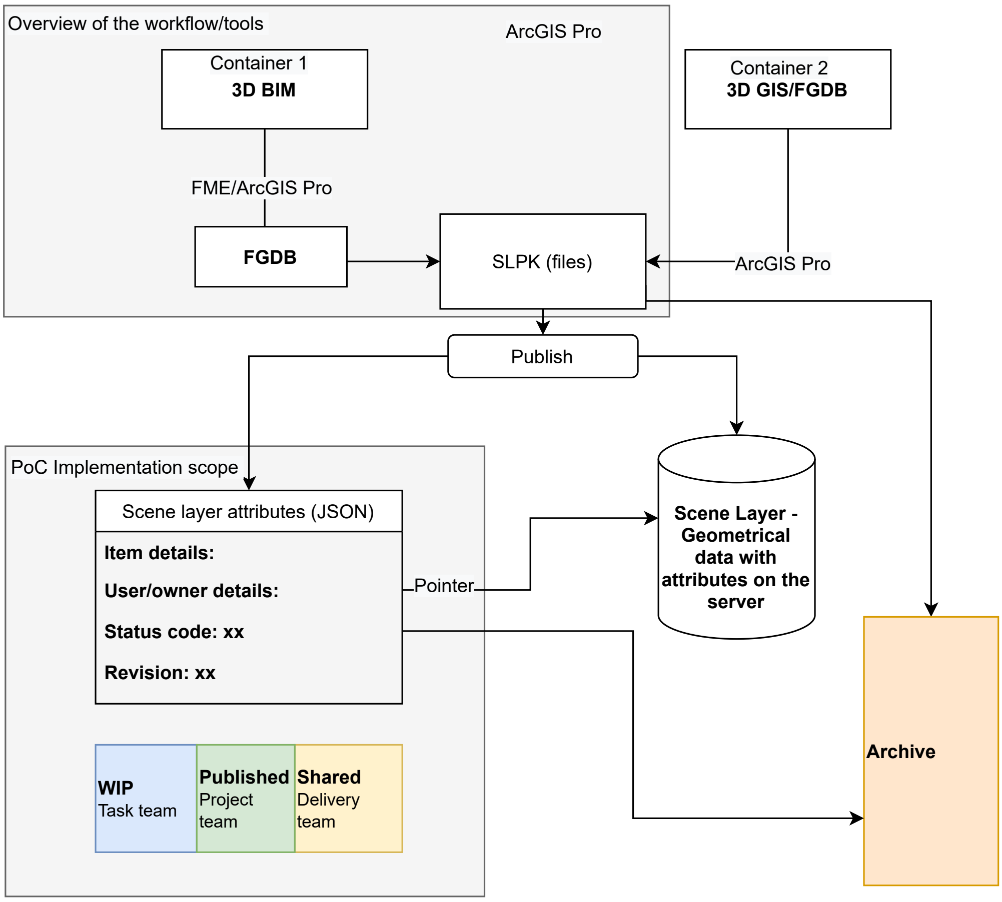
Items in ArcGIS Online, such as the I3S scene layer, are RESTful web services that support responses in JSON format. Each item in JSON response contains JSON objects (called response properties or fields) such as title, snippet, typeKeywords, and tags. These fields can be used for administrative and management purposes, e.g., the snippet object (field) contains a brief description of the item. Figure B.3 is a JSON response example of an I3S item. The implementation will utilize the fields of these JSON responses to discuss the CDE components application.

5.2.1 Use case

There are two options for publishing an SLPK file as an I3S scene layer in ArcGIS Online. Option 1 is publishing from an ArcGIS Pro scene directly using *share as web layer* tool. Whereas option 2 is *Publish from a scene layer package* created in ArcGIS Pro (illustrated in schema 5.2). Option 2 is recommended to guide the implementation for two reasons: first, the geometrical data are

[4] https://doc.arcgis.com/en/arcgis-online/share-maps/groups.htm URL date: 2021-05-16

[5] https://doc.arcgis.com/en/arcgis-online/reference/search.htm#ESRI_SECTION1_84780995F34046ACA797CF6A7B171437 URL date: 2021-05-16



The implementation scope (lower left box) focuses on the CDE components implementation. For the scope of this thesis, overview of the supported 3D BIM data and the workflow/tools available for converting an (*.ifc) file to a SLPK file is presented (upper left box) in section 5.1.

Figure 5.2: Schema illustrates the use case utilized to discuss the CDE components implementation according to ISO 19650-1&2:2018.

stored in one SLPK compressed file, which makes it easier to store these data for versioning purposes (one of the CDE components). Second, restoring the data from a stored SLPK file can be easily done by uploading it to ArcGIS Online and publishing it without the need for any software (unlike option 1, which requires ArcGIS Pro). When publishing the SLPK file in ArcGIS Online, the geometrical data (with its symbology) are mapped to the database on the server, and an item (REST resource with its own URL in the portal) is created. As mentioned in the previous paragraph, the item contains the item properties as JSON objects such as *Title*, *Snippet*, *Description*, *Tags*, *and Thumbnail* in addition to *type* and *type keywords* (see figure B.3 for an example) [6].

[6] https://developers.arcgis.com/rest/users-groups-and-items/items-and-item-types.htm URL date: 2021-05-16

5.3 Implementation of the CDE components in ArcGIS Online

At this point, it has been defined that the CDE environment is represented by a Group feature, whereas an information container is a single scene layer referred to as an item in ArcGIS Online. In the following subsection, the study shall walk through the components one by one and make the implementation decisions. Note that, for implementing ISO 19650 standards, each country, region, or even company might have its conventions. This work uses the UK national annex conventions as they are the most popular and used conventions.

5.3.1 Each information container in the CDE has a unique ID

The unique ID of an information container should be according to an agreed-upon and documented convention. This means that for each CDE solution, the unique ID should: 1- identify the data and give an indication of the content of this data 2- ensure that there is no duplication in the data (an information container). In the ArcGIS Platform, each item (information container) has a unique ID by default which, if used, is supposed to be enough to ensure that there is no duplication in the data. However, the implementation can use item titles since it is not possible for two items to hold the same title within one organization in the ArcGIS platform. Another option is to use a combination of ItemID and Title since the use of the codified title can be essential to identify an information container and/or its content. More about identifying information containers and their content by metadata is explained in the third component section (5.3.3).

5.3.2 Information container's states

As mentioned in section 2.1.3, during the information workflow in the CDE, each information container development undergoes WIP, Shared, Published states. The workflow is controlled through an archive that contains a version history of an information container, see 2.5.

The user can configure content categories on the organization level or the Group level in the ArcGIS platform. Group categories offer more flexibility as the owner has the required privileges to create categories according to the project requirements. Also, it allows the user (group owner) to have better control over the items and members' roles in the group, which is another component of the CDE. Therefore, Group categories are a better option to configure the ISO 19650 states and organize the content accordingly (see figure

5.1 for illustration).

5.3.3 Information container's attributes: status, revision, and classification

Metadata assignment is the key to managing the information containers. Even states and information container IDs are considered metadata that describes and refers to their content [Kemp, 2019]. ISO 19650-2 clause 5.1.7 requires each information container to be associated with additional attributes *status*, *revision*, and *classification* assigned as metadata:

- **Revision:** during the development of an information container, it is important to keep track of its version and revision history. The version and revision history should also register the details of the party who has received sharing privileges of the information container. The revision system should follow an agreed-upon standard. UK national annex provides a system that is explained in figure 5.3, and in [SymetriUK, 2020]
- **Status codes:** the status code is assigned to the information container to indicate the suitability of the information, e.g., suitable for coordination. The reason for assigning the status is to make clear to the recipient what the information container should (or should not) be used for. Table 2.1 shown here contains the standardized status codes recommended in the UK national annex. The combination of revision and status codes is used to track down the change in the content and to capture the appropriate use of it [praktijkrechtlijn, 2020].

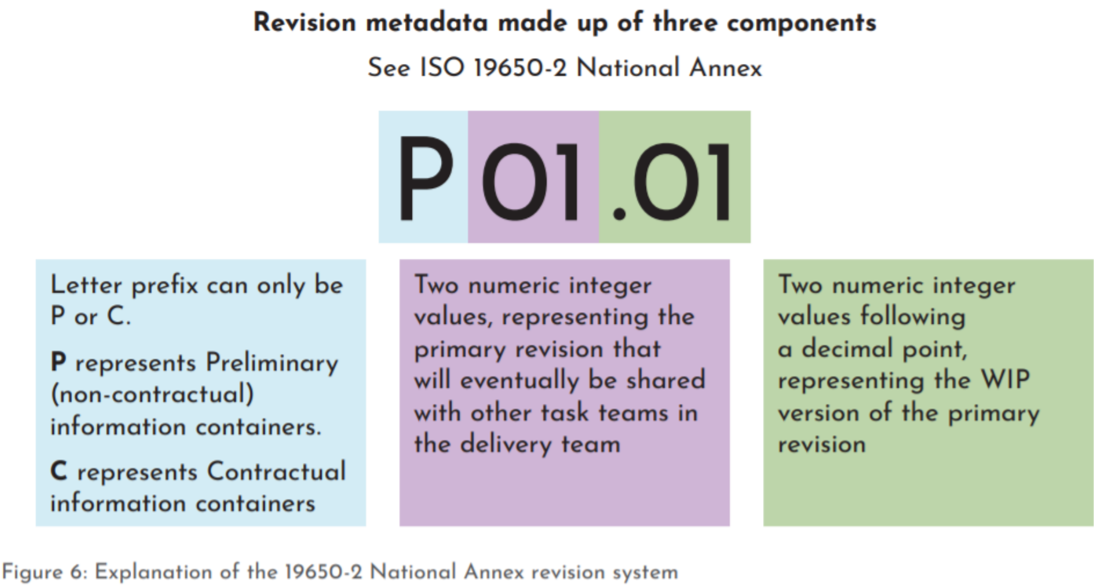


Figure 5.3: Revision system of UK national annex, [Kemp, 2019]

- **Classification:** container classification methods are defined in the information standards of a given project. Clause 5.1.7 in the ISO 19650-2 document specifies that classification should be following the framework defined in ISO 12006-2. Uniclass 2015[7] classification structure, referenced in the UK national annex, contains a set of classification tables that can be used to categorize information for multiple purposes [Kemp, 2019].

Since these three components are regarding metadata allocation, it is good to note that the CDE solution should consider two aspects when the assigning the metadata:

1. How to identify an information container and/or its content.
2. How to transfer information containers, with their (desired) metadata, between CDE solutions if the project's more than one CDE solution e.g. for the task team and one for appointing party.

Note that ISO 19650 standards allow metadata assignment beyond the ones specified in Part-2 (see figure 2.7).

When searching for items (information containers) within a Group (CDE) in ArcGIS Portal, we can filter the items based on the configured group categories [8]. Therefore, metadata could be configured in the categories and subcategories.

[7] https://www.thenbs.com/our-tools/uniclass-2015 URL date: 2021-07-16
[8] https://enterprise.arcgis.com/en/portal/latest/use/search.htm URL date: 2021-07-16

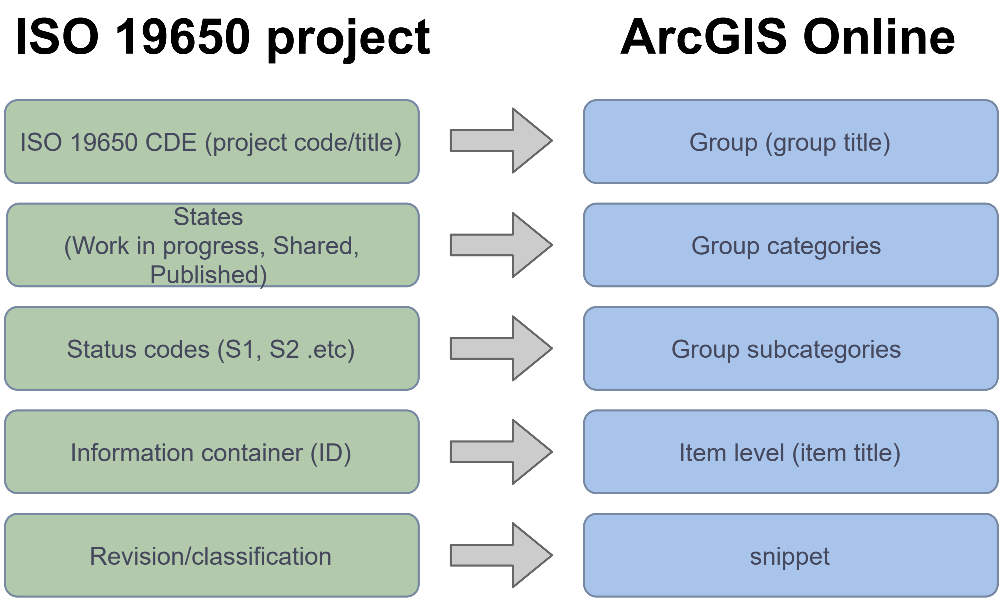


Figure 5.4: A CDE represented in ArcGIS Online as a Group: metadata required for an information container and how they are assigned partly on the Group level and partly on the item level

Also, when performing a search for items, the default fields that the search operation looks into are title, tags, snippet, description, type, and typekeywords. So, metadata can be assigned to an item in any of these fields or by Group categories. Type and typekeywords fields are unmodifiable by the user. However, they can be used for refining the search. Therefore, the user could use one or more of the fields tags, snippet, or description[9]. The snippet field contains a brief summary of an Item, and its content is visible when browsing through a group content. So, it allows finding and identifying an item fast, which serves the purpose. Therefore, the snippet field is the best option among these fields. Figure 5.4 illustrates the decisions made to assign the CDE's required metadata using the Group feature in ArcGIS Online. It shows how the metadata assignment is done partly on the Group level and partly on the item level. This solution should fulfill the requirement of the first three components of the CDE solution.

5.3.4 Recording of the information containers' history (user, date, data, and metadata allocated) when transitioning between states.

As mentioned in the attributes paragraph 5.3.3, it is required to keep track of the revision, status, and versions of each information container. Besides the data itself, the audit trail should also include the user details and the action date. ISO 19650-1&2:2018 also recommends that the audit trail register the user details of the party(s) who has received the data (the party with whom the data has been shared) If we break this down, there are two kinds of records:

Record of the data change (versions of data itself), e.g., every time the new objects have been added to the design in the WIP state, it should be registered what and who has added the change. In our case, the scene layer (information container) is updated with new data through uploading a new SLPK file. The SLPK file contains the scene layer and its data. So, keeping a version of the data itself could be simply done by storing a copy of this SLPK file in a side repository (the archive) before uploading (see figure 5.2 for illustration). Restoring this data can be done by picking the SLPK file (of the desired moment in time) from the repository and update the corresponding scene layer with the data in this file. Updating the scene layer can be done using *replace layer* tool so that the layer properties (Title, Snippet, Tags, the and Url endpoint) can be maintained. Roberts [2020] present the steps for using *replace layer* tool. This brings us to the second type of data.

[9] https://enterprise.arcgis.com/en/portal/latest/use/advanced-search.htm URL date: 2021-07-16

Record of the workflow change, e.g., every time an item (information container) has been pushed from WIP state to Shared state, the item should be updated with the new revision details and status code. So, it is required to register the details of who has pushed the item and when, the previous and the current state, revision status, and which state to which one.

In the ArcGIS Platform, each item (scene layer or information container) has a comment section in the Overview tab (should be enabled by the organization). A way of tracking down the history of an item is by simply using comments objects of the (JSON) response. So, a comment can be added on the item level (information container) for each action or transitioning of an item. By default, each comment registers the username of the user and date. All additional and required information can be added as a comment. Figure B.2 shows an example of the comments' API (JSON) response and UI in ArcGIS Online. The comments section allows version history track down available for the user.

To summarize, a full track of data and metadata can be maintained if the following is stored in the archive (any external or internal storage technology):

- A copy of comments section (in (JSON) format) and the item properties (also in (JSON) format), see figure B.3, after each action taken, and
- A copy of the SLKP files (actual data) uploaded in each data update.

This conceptual solution for audit trailing (versioning) the information containers could be beneficial, supposing that it is desired to audit trail the data in GIS format (here SLPK and I3S). However, the exact functionalities that store and restore these data are beyond the scope of this thesis.

5.3.5 Controlled access at an information container level.

For security reasons, it is crucial to consider different access permission levels to information containers when selecting the potential CDE solution. For example, an information container could be shared at an individual, organizational, or public level.

The ArcGIS platform offers a variety of features that can be used for access privileges purposes. For instance, the Groups feature used as a CDE allows the user to choose the view level, who can join the group and contribute content, and/or use distributed collaborations. Items (information containers) can be shared on different levels, own, organization, or public. Moreover, different privileges levels (default or custom ones) can be granted to the user (per user type) according to their role [10]. Using these features and functionalities allows different levels of privileges to user or user-type according to the given situation.

5.4 Proof of concept (PoC) implementation

The implementation decision mentioned above regarding metadata allocation can be made manually by the user. However, there are many steps for metadata updates to be done after each action. When decisions are made on where to assign metadata and what privileges each role has over which item, functionalities that automate these processes could be implemented. These functionalities can be beneficial in minimizing the mistake rates and/or deployed in Web-based applications or a customized user interface of the CDE solution. Implementing such functionalities can be done using ArcGIS's APIs. In this GitHub repository, a few PoC functions are created using the aforementioned decisions regarding metadata assignment (see figure 5.4). The functions are:

- **ISO 19650 Group** function - configures a Group according to the ISO 9650 UK national annex conventions.
- **Push** function - does the transitioning of an item between states and updates its metadata accordingly. This function adds a comment (as a register of the push action done) in the comments section. This could be used for tracking of the workflow of the information container.
- **Initialize metadata** function - initialize the required metadata of the items in the configured ISO 19650 Group.
- **Approve** function - When an item is transitioned between states, e.g. from WIP to *Shared*, Approve function can be used to change the metadata **Approved: false**, to **Approved: True**.
- **makeReferenceData** function - makes projects related data available for usage or referencing by updating them with required metadata.
- beside these 5 main functionalities, there are many functions created that may be of help for starting own workflows. These functions has comments that explains what they do in the main Python file *`ArcGIS_GroupAs_ISO19650_CDE.py`*, for example, the **updateRevision** and **addComment** functions, (this GitHub repository contains further details regarding the implemented functions).

[10] https://doc.arcgis.com/en/arcgis-online/reference/roles.htm#ESRI_SECTION1_4FF9051EFB814C249AB26B0ACFF7C79F URL date: 2021-07-16

For implementing these functionalities, ArcGIS Rest API is used in the Python scripting language. These can be used directly or as a reference to develop functionalities for their own workflows. The idea behind creating these functionalities is to be utilized in Web-based applications, e.g., ArcGIS Hub. To clarify, this Hub page is created as a template of a user interface example that illustrates the CDE workflows. The Hub is configured to have sub web pages representing the states (Work in Progress, Shared, Published). The main page containing the reference data (open data available and/or own existing data related to the project). The main page could also contain the ISO 19650 protocols followed during the project. The Hub also allows different sharing levels privileges besides that the access privileges of the items (information containers) in it are still applied. Note that all items in the Hub are for illustrations purposes. So, they are not permitted for another sort of use. For usage and a complete description of the functions created to manage the workflows in the Hub, refer to the GitHub repository and/or use this Python Notebook directly in the ArcGIS portal.

Results & discussions 6

In this chapter, we will assess the results of the CDE components implementation from chapter 5, then we will discuss the assessment for each component. Given its relevance, we will briefly review and discuss the results of the preliminary investigation.

6.1 HWBP (case study) and ISO 19650 standards

In section 3.2.2, the preliminary investigation on the HWBP has identified a list of challenges encountered during the information management process in infrastructure projects. The challenges identified in the investigation do not necessarily apply to every case. The interviews have shown that, in some projects, the standards have reached an advanced level of maturity. However, the fact that the majority of participants in the investigation (the innovation sprint and interviews) were familiar with ISO 19650-1&2:2018 standards made them indicate the challenges that could possibly be overcome by adopting ISO 19650-1&2:2018 standards. As the identified challenges are generally faced in different HWBP projects, they could also be generalized to similar (infrastructure) projects.

The investigation has also addressed the role of Web GIS in the information management process of infrastructure projects. The role of (Web)-GIS in HWBP projects (case study) can be summarized by one sentence, said by V, N from Tauw, "everything starts and end on the map". In HWBP projects, Web GIS and GIS information are used for spatial analysis during the development of information in projects. V, N from Tauw indicated that, in some projects, a BIM model is converted to I3S scene layer and only delivered as a part of the GIS data (in the Published state according to ISO 19650-1&2:2018) as this can be a clause in the contract.

The exact role of Web GIS differs per project, and different set-ups for managing the information involve Web GIS. Therefore, the exact potential role of Web GIS needs to be addressed on a project level. For the motive of this thesis, it was sufficient to conclude that the final spatially enabled information (BIM and GIS) are delivered in GIS format and stored in Web GIS as web services. However, it is still unclear when and how BIM data are converted to GIS data during the process or the other way around, which may be case-specific. Furthermore, it was essential to understand that Web GIS is involved in the information management process throughout the project for spatial analysis. Therefore, the need for CDE aligned with ISO 19650-1&2:2018 is required for compliant projects.

This thesis reviewed ISO 19650-1&2:2018 in the context of the HWBP projects. The review covered two main elements of ISO 19650-1&2:2018 standards. Section 3.3 has elaborated on how these two elements optimize the information management process. The optimization is on both the organizational (roles and activities) and technical (CDE solution) aspects. The investigation has also explained how ISO 19650-1&2:2018 would help to overcome the identified challenges of the information management process in the HWBP.

The first element is the roles defined in Part-2 and the eight activities (project) stages. In the review, only a few activities regarding setting up the CDE solution were reviewed. The review highlighted how specified responsibilities assigned to each role at each activity would optimize the collaborative management of information in the HWBP projects. It has explained how these roles and activities add pressure on the waterschappen and contractors to live up to the responsibilities assigned to their roles. For example, the waterschappen as the appointing party should deliver information requirements to specify how the information should be delivered, in which format, and what is the future use of it. For the contractor (as the appointed party), the information requirements clarify how to produce the information, what format, and what criteria to use. Therefore, the information of the final product is optimized and delivered for usage in the next stage of application. This also means that post-processing is not required for the information.

The second reviewed element of ISO 19650-1&2:2018 is the CDE concept. Section 3.3 has explained how the CDE concept, through metadata systems, enables easier and faster access to both the in-production information and reference data available prior to the project. It has been explained how the CDE enables an oversight over the production of information. This allows the appointing party and the lead appointed party to intervene on time and prevent wasting time on worthless work. Therefore, the thesis has examined the possible implementation of the CDE components for web services in Web GIS.

6.2 CDE components - implementation assessment & discussion

This thesis has reviewed several aspects of the CDE concept, including the information workflow, the technical solution, and the CDE components. This covers representing an information container as a single I3S web service. Section 5.1.3

discussed the possible options to convert Civil 3D (CAD data) to I3S web services as information containers. Furthermore, the review has focused on the CDE components from clause 5.1.7 in Part-2 (listed in section 2.1.4). Therefore, section 5.2 discussed possible solutions for each component for I3S web services on the Web.

6.2.1 Implementation assessment

As mentioned in the methodology chapter (4.3.2), the assessment is based on a checklist of key points/requirements defined from clauses in Part-2 regarding the CDE solution. The assessment evaluates the results of this thesis and the implementation in the ArcGIS environment (5.2) on the CDE concept. This will be done in the form of a rubric table (see table 6.1) that will evaluate the implementation as well as the implemented PoC functionalities. Each clause/requirement of the list get a score of ***Full, Medium, Low or NA (not applicable)*** for both the reference implementation discussion and PoC functionalities.

Clause(s)/ requirement	**Score/explanation**	
	Reference implementation in ArcGIS Online	**PoC functionalities**
(5.1.4)/ Have status code standards & revision system been set for the project's information standards?	*Full* / UK national annex status codes standards (2.1) and revision system (5.3) were used.	*Full* / A flowchart developed for the technological capabilities/requirements (see 4.3).
(5.1.4)/ Has a classification system been set for the project's information standards?	*Medium* / Tackled on high level. However, no specific classification system has been defined. So, only where the information container's classification can be allocated for scene layers (information container).	*Full* / Functionalities to allocate classification metadata for web services but not according to a defined system.

(5.1.4)/ Has the ID codification standards been set for information container in the project's information standards?	*Medium* / Tackled on high level. However, no specific ID codification standards has been defined. Only where and how to approach information container's ID allocation for the scene layers (Web services) in Web GIS.	*Low* Not tackled. Only the web service's ID (item ID in ArcGIS environment) is used to ensure no duplicate of the information containers.
(5.1.5, 5.5.2)/ Have possible CDE solutions been looked into to ensure supporting the agreed-upon metadata allocation?	*Full* The implementation discussion has thoroughly reviewed potential solution for metadata allocation of the scene layers as information containers.	*Full* / Fully functional with optionally changing the fields where metadata allocation happens.
(5.1.5, 5.3.2, 5.5.2)/ Has different access privileges (at an individual and organizational level) been considered for security reasons?	*Medium* / The implementation discussion has presented an overview of access privileges feature supported in the ArcGIS environment.	*Low* / not tackled
In case of having multiple CDE solutions, has the following been reviewed? 1- Metadata assignment transfer between the CDE's, 2- (Manually or automatically) seamless pass of the information container through each CDE solution	*Low* / Out of scope. However, an overview of the BIM data formats supported in the ArcGIS environment has been presented.	*NA* / Not tackled

Table 6.1: Rubric assessment of the CDE implementation discussion (5.2) and the proof of concept functionalities (5.4)

6.2.2 Metadata allocation components

Generally, this thesis tackled all CDE components. However, the implementation paid thorough attention to metadata allocation. The metadata allocation components include the information container's states (WIP, shared, and published), information container's ID, and the information container's attributes (revision, status codes, and classification). The information container attributes component requires defined systems. Therefore, this thesis has explained and utilized the systems of British national annex conventions. The *Revision* (see figure 5.3) and *Status codes* (see table 2.1) systems have been adopted as available. The classification attribute differs per project or a given case.

This means that, based on the given project, Part-2 recommend selecting a classification table from Uniclass 2015 classification structure following the framework defined in ISO 12006-2. Since there is no specific case tackled in this thesis, no system or table was introduced. However, the implementation tackled the assignment of classification attribute to the information containers.

A flowchart has been developed for the technological requirements that enable information container workflows (see figure 4.3). The flowchart capabilities were developed based on the British national annex conventions for the *Revision* (see figure 5.3) and *Status codes* (see table 2.1) systems. Furthermore, the flowchart illustrates where and how the check/review/approve capabilities are necessary for the workflow. The reference implementation in ArcGIS Online utilized this flowchart to develop solutions for the CDE component and implement PoC functionalities.

The reference implementation covered applying the CDE components (see section 2.1.4) in ArcGIS Online as a Web GIS Platform. Therefore, the Group feature available was utilized as a standalone CDE and I3S scene layer items represented information containers. The implementation has discussed a possible technical solution for the CDE components and reviewed ISO 19650-1&2:2018 language around the CDE in the context of RESTful web services.

The CDE components implementation can be utilized to enable ISO 19650 workflows and configure the final technical solutions in the ArcGIS systems as a standalone CDE. The implementation provides solutions and functionalities for

- Transitioning of information container between states *WIP, Shared, and Published*.
- Assigning attributes, status codes, revision, and classification to the information containers. Status code and revision systems are functioning according to the British national annex.
- Assigning the information container ID
- **approve** function of information container function.

These functions can be utilized to configure a full workflow and technical solution for container (2) in figure 4.2 in ArcGIS Online. However, for container 1 (BIM data), the implementation could be utilized for only the Web GIS side of the technical solution in integrated workflows.

The implementation discussion showed that there are a variety of options for implementing the first three components regarding the metadata allocation: *Information container's ID*, *information container's states* (WIP, Shared, and published), and *attributes allocation (revision, status codes, and container classification)*. The chosen solution (figure 5.4) fulfills the standards mentioned in the ISO 19650-1&2:2018 the most. However, other choices may be a better fit for different applications or workflows. For example, title or description fields could be used instead of using a snippet field (object in the (JSON) file) for metadata allocation.

Furthermore, the proof of concept implementation functionalities (section 5.4) focused on the three components of metadata allocation. The results are examples of functionalities that could be utilized to configure CDE technical solutions the ArcGIS Platform (Web-based application) according to the British national annex conventions. In ArcGIS Online, all items (RESTful web services in JSON response) contain the item ID, title, snippet fields. Furthermore, all types of items, as I3S items, can be managed by the Group feature available. Therefore, although the proof of concept implementation has focused on web services of type scene layers, the architecture of the ArcGIS platform allows using these functionalities for most types of web services supported in ArcGIS Online.

6.2.3 Record of information container history

Regarding the *record of information containers history* component, the implementation discussion presented a solution for a chosen workflow (use case) of 3D data as SLPK and I3S web services (see figure 5.2). The conceptual solution explained how to store the 3D data in SLPK format and store the history metadata, including user details and dates in (JSON) format. Although the metadata ((JSON) file) provides an overview of the information container history (audit trail), the solution on this component remained high level, especially regarding the data stored in the Archive. The solution was based on a suggested workflow for uploading the GIS data (converted from BIM or GIS) into ArcGIS online (illustrated in figure 5.2). More specific information workflow (use case of a project) is required for low-level implementation. A more concrete case (information workflow) should be able to specify what/where the data should be stored (archive/repository) and what data format is desired to be stored in the repository. For example, it may be more desirable for BIM data to be stored in the Archive before converting and uploading to Web GIS. Furthermore, the solution on this component disregarded the process where the data is being generated or converted from BIM data.

6.2.4 Different access privileges levels

Finally, regarding the *different access privileges levels* component, the implementation discussion has presented a variety of features in ArcGIS Online that allow the user to deploy the desired level of access to information containers for different applications (see section 5.3.5). According to any given case, different access privileges levels can be configured and given to the parties involved based on their roles in the projects.

Conclusions 7

This chapter will review the research questions of this graduation thesis to evaluate the degree in which they have been addressed. Then, we will define the contribution to the state of art along with the reflections and limitations of the research. Finally, topics for future work are suggested with respect to the limitations.

7.1 Research overview

This section reviews the research questions defined in section 1.1. Then, answers to the sub-questions will elaborate on the findings and the degree in which this research has addressed each (sub)-question.

Main research question

> *How to implement a CDE in Web GIS to enable ISO 19650-1&2:2018 compliant workflows for web services?*

In this thesis, chapter 5 reviewed the CDE components objectives and discussed their implementation in accordance with British national annex conventions BS EN ISO 19650-2 - Delivery phase of the assets [2018]. Therefore, the ArcGIS Online environment represented the Web GIS platform for the reference implementation discussion. The final CDE solution was based on features available in ArcGIS Online, such as the Group feature, which represents a CDE environment. Proof of concept functionalities was implemented regarding the final suggested solution for metadata allocation. The results presented in section 6.2.2 show that the suggested solution for metadata allocation components applies for I3S web services as well as other types of web services (items in ArcGIS online).

The resulting solution and the implemented PoC functionalities could directly be utilized for configuring the CDE technical solution for a given information workflow in ArcGIS Online. Therefore, ArcGIS Online users that wish to adopt the British national annex conventions BS EN ISO 19650-2 - Delivery phase of the assets [2018] could directly benefit from the implementation to configure their final CDE technical solution.

The implementation section explained the objectives and gave ideas on how to tackle each component for web services. Moreover, in the results section (6.2.2), the assessment rubric (table 6.1) provided oversight of all the covered aspects of the CDE solution. The proposed CDE components implementation may be unfitting to the needs for a given set-up or information workflow. In such cases, the discussions can give a reference for the application of the CDE components for web services in ArcGIS Online. Users who work with a different Web GIS platform can also utilize the reference implementation discussion. It helps in understanding how to approach the implementation of the CDE components for web services. For example, implementing the metadata allocation components requires an understanding of the search engine in the Web GIS platform to leverage the advantages of ISO 19650-1&2:2018 standards (read more in answer to sub-question 2).

Sub-question 1

> *What represents an information container within the CDE on Web GIS?*

Section 5.1.1 compared two options available for publishing I3S scene layers (web services) to ArcGIS Online. The selected option is where I3S is published from its corresponding SLPK file (containing the same data in a single compressed format). Then, section 5.1.3 concluded that each discipline (objects of one discipline) should be published as a single I3S scene layer. This ensures that each task team works on their information container independently. Therefore, this thesis used a single I3S scene layer and its corresponding SLPK to represent a single information container containing a discipline.

The recommended representation of the information container was based on the ISO 19650-1&2:2018 standpoint. However, ISO 19650-1&2:2018 offers a level of freedom for representing an information container according to the given case/project. So, each task team in the project should have an independent information container workflow. Therefore, other options for representing the information container are valid as long as they comply with ISO 19650-1&2:2018 and offer independent workflows for different task teams.

Sub-question 2

> *How should the information containers' states and attributes be implemented to have the advantage from the ISO 19650 compliancy?*

In chapter 4, this thesis provided a flowchart that depicts information containers' states and attributes systems according to the British national annex conventions. Then, in chapter 5, the implementation discussion explained the objectives of each component of the CDE. The information container's states and attributes systems are interrelated in a way that allows very controlled workflows. This includes the ability to identify the content of each information container and its state in the CDE. Moreover, the discussion explained how attributes systems (revision and status codes) provide an insight into the information container history (who, when, and what) and its usage suitability (who can use it and what for). Therefore, for leveraging these three advantages, the best solution should allow visibility of the allocated metadata. It should also allow searching and filtering the data based on one or more of the allocated states and attributes.

7.2 Contribution

This thesis has addressed several aspects regarding ISO 19650-1&2:2018 and the CDE solution in Web GIS. Although some aspects may not be novel, this graduation research can contribute to the state of art by:

- Elaborate review of ISO 19650-1&2:2018 standards in the context of the HWBP projects that include working with GIS and BIM data.
- Highlighting and proving the need for CDE solutions in Web GIS to enable ISO 19650-1&2:2018 compliant workflows.
- Comprehensive insight into the application of metadata allocation components, which includes information container states and attribute systems to enable managing web services (as information containers) in Web GIS.
- Reference implementation for the CDE components application in ArcGIS Online as a Web GIS platform.

7.3 Discussion

In this thesis, the implementation of CDE components was based on the assumption that an information container is represented by a single I3S web service (scene layer item). This allowed utilizing the management features/-tools available in ArcGIS Online (Web GIS) for the reference implementation. However, if a given case states that information containers are the objects within the database, e.g., each element of the construction structure is an independent information container. In such cases, the implementation of metadata allocation components should look into objects attributes within the I3S layer structure in the database. This would be more complex to realize, and the implementation approach will be completely different. The point to be noted is that each case states a different approach for implementing the CDE components and technical solution.

ISO 19650-1&2:2018 standards are abstract. Even if technological solutions are available to configure and support the CDE workflows, it is critical to have a command of the objective of each component for the implementation. In this thesis, the reference implementation deployed features/tools, which are already available ArcGIS Online for data management, to configure the final solution of CDE components. Therefore, for realizing the CDE workflow and technical solutions, it is essential to have a good understanding of the ISO 19650-1&2:2018. Then, research looks into deploying features/tools available within the used (Web GIS) platform for configuring the technical solution to support any proposed information workflows.

ISO 19650-1&2:2018 standards claim to standardize the collaboration in projects information management. However, we have learned that each country or region has its own annex, e.g., the British national annex, which we have used for the reference implementation in this thesis. It is not clear how organizations can internationally collaborate when they have adopted different conventions/annexes. These arguments were not a critical aspect of this research. However, these questions were raised during the research process and remained without answers.

7.4 Reflection

This thesis has addressed the importance of Web-(GIS) platform and GIS data for information management workflows of (infrastructure) projects. This has shown the need for applying ISO 19650-1&2:2018 standards for enabling compliant and collaborative information management workflows. By doing so, this research has established the link between the (Web)-GIS platform and ISO 19650-1&2:2018, which was originally developed for BIM data.

Furthermore, this thesis has discussed solutions for implementing CDE that could be utilized to enable ISO 19650-1&2:2018 workflows for I3S web services in Web GIS. The results of the implementation may be of interest for organizations that wish to integrate Web GIS in the information management processes in projects aligned with ISO 19650-1&2:2018. Regardless of the adoption of ISO 19650-1&2:2018, the results may also be of interest for data managers or companies who wish to optimize the information management overall in Web GIS. They could benefit from ideas and techniques provided around ISO 19650-1&2:2018 standards and the implementation of CDE components.

This thesis may be of interest for construction companies and waterschappen to consider and further research the adoption of ISO 19650-1&2:2018 standards for collaborating in HWBP projects. The potential optimization of collaborative information management in projects would save much time and money and deliver better quality and well-managed data. Therefore, it may be of great interest to research the adoption of ISO 19650-1&2:2018 for around 20-25 years of collaboration among waterschappen and companies in the HWBP projects.

7.5 Limitations

During this research, there have been some imitations encountered which will be mentioned in this section.

- The main limitation of this research is that the topic comes from market demand regarding the question "how can we benefit from ISO Series and how can we apply it for GIS data in the (Web) GIS platform". ISO Series standards, which were recently released (in 2018), are abstract. And, there is hardly any research found that addresses ISO 19650-1&2:2018 standards for GIS or GIS and BIM integrated workflows. Therefore, it was not possible to base this study on earlier research. Hence, much effort was put into understanding and defining the potential role of Web GIS in enabling ISO 19650-1&2:2018 compliant workflows.

- There was no concrete information workflow (use case) for GIS and BIM data that helps specify concrete questions e.g, data type and how is it desired to have BIM data in Web GIS (what represent and information container). Therefore, it was not possible to develop the CDE information workflow solution and then address the CDE components & technical solution. Instead a general case for 3D data coming from BIM or GIS data had to be chosen to guide the implementation discussion on the CDE components in Web GIS.

- Even though all CDE components have been tackled in the implementation discussion, within the time-frame of this research, it was only possible to address metadata allocation in details and with proof of concept functionalities. Yet, this requires more work after having a concrete information workflow developed according to ISO 19650-1&2:2018 standards for both GIS and GIS BIM integrated processes. Only then, all CDE components could be addressed accordingly.

- It was not possible to gain in depth details about any standards and attributes systems used by the parties involved in the HWBP for projects information management. Therefore, it was not possible to compare these with the ISO 19650-1&2:2018 standards. As a result, the British national annex conventions were utilized to specify information container attributes systems for the implementation discussion.

7.6 Recommendation for future work

- As mentioned in the previous section, the main limitation of this research is the lack of a specific information workflow to guide the research process. If provided, future study could develop the information workflow solution more concretely for GIS data as well as BIM data in an integrated workflows. Then, for applying the technical solution and creating a CDE, the work done in this research can be used as a staring point.
- In this research, solutions on metadata allocation in Web GIS were presented. Future study may address the data transfer between the (cloud based) BIM platform and the (Web) GIS platform with its metadata. This should include defining what an information container represents in the BIM platform. Furthermore, it should specify how the information containers are converted to the corresponding GIS data as information containers in the GIS platform. This is considered an important step towards finding the CDE workflow and technical solution of BIM data converted to GIS data (or in the opposite direction).
- Comparing the current standards used by organization(s) or countries with ISO 19650-1&2:2018 standards may be an important step towards better understanding what/how to benefit from ISO 19650-1&2:2018 standards. For example, the Netherlands has the NLCS (Nederlands CAD standards) which contains principles for metadata allocation, digital drawings, and the files structure for the Dutch GWW-sector (Grond, Weg, Water ("ground, roads, water") sector). A study that compares the Dutch NLCS (Nederlands CAD standards) with ISO 19650-1&2:2018 may address the possibility of developing the Dutch national annex of ISO 19650-1&2:2018 standards.

Reproducibility self-assessment

A

A.1 Marks for each of the criteria

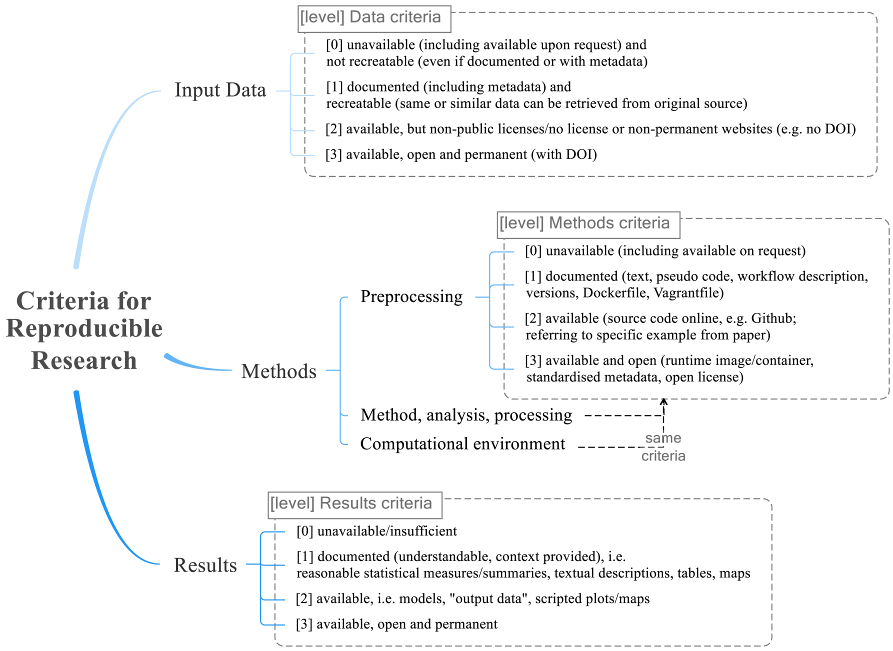


Figure A.1: Reproducibility criteria to be assessed.

A.2 Reproducibility of thesis/results

Criteria	score
input data	1
preprocessing	3
methods	3
computational environment	3
results	3

Table A.1: Self-assessment of scores regarding the criteria presented in

All results, tools, and data used in this research are publicly available. The methodological approach of this thesis can be applied for different case studies and/or a Web GIS Platform. Although Esri Nederland provided full access to their platform for the implementation in ArcGIS Online, similar work can be tested or developed using a free developer account that grants access to ArcGIS Online. The following sections provide an overview of the used tools and data.

A.2.0.1 Tools

For the reference implementation that enables a CDE workflow in Web GIS, Esri's ArcGIS Online is used as a Web GIS platform. The group feature is used to represent a CDE environment. ArcGIS Hub, which is a configurable website interface, is used for visualizing the content and workflows of a CDE. The hub has also helped test the created proof of concept functionalities. This GitHub page is used for hosting the codes/functionalities which is made publicly available. In Python scripting language, the Rest API for ArcGIS was used to create the functionalities. This Python Notebook was also implemented to be used directly in the ArcGIS Online portal.

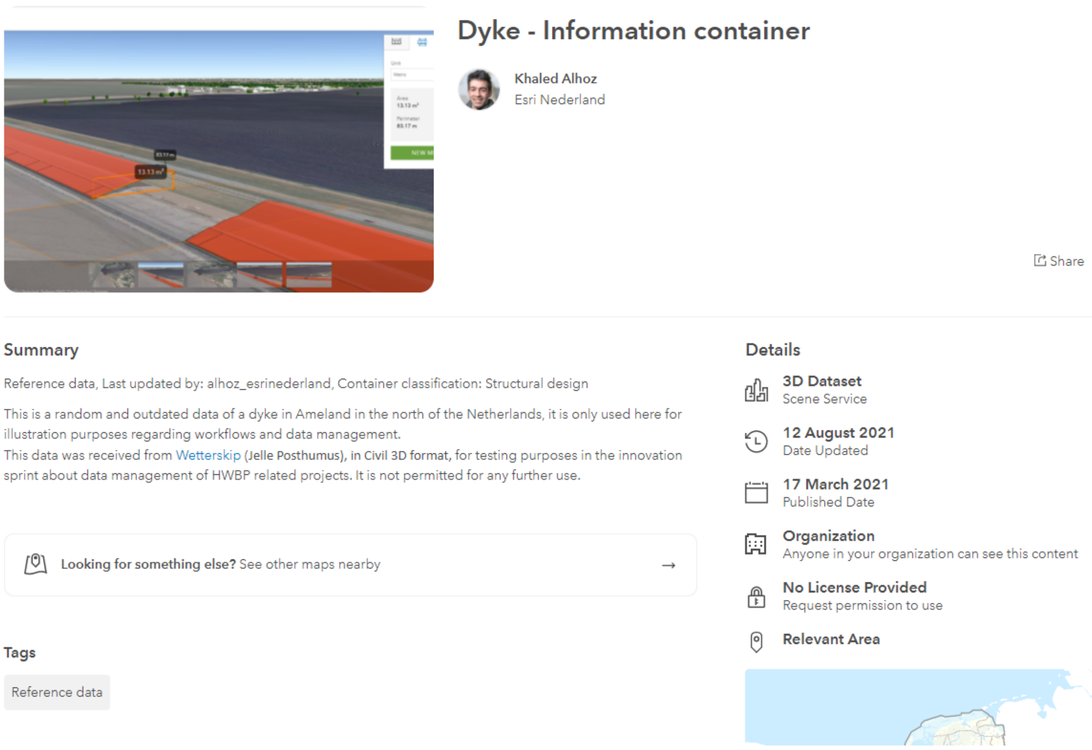
A.2.0.2 Data

For the purposes of this thesis, any data can be used for developing the workflow and testing the implemented tools. There are many I3S web services (scene layers) that are openly available and can be used. In fact, due to the architecture of ArcGIS Online and how Web services are structured, the created functionalities work for most types of web services supported. However, there are Civil 3D (*.dwg) model of a dyke in 2D and 3D related to the HWBP, and authorized for testing. The Civil 3D model was converted to scene layers which have been used for testing the implemented functionalities. The data was also used in the implementation discussion to give recommendations on how BIM data could be converted to scene layers within ISO 19650-1&2:2018 framework.

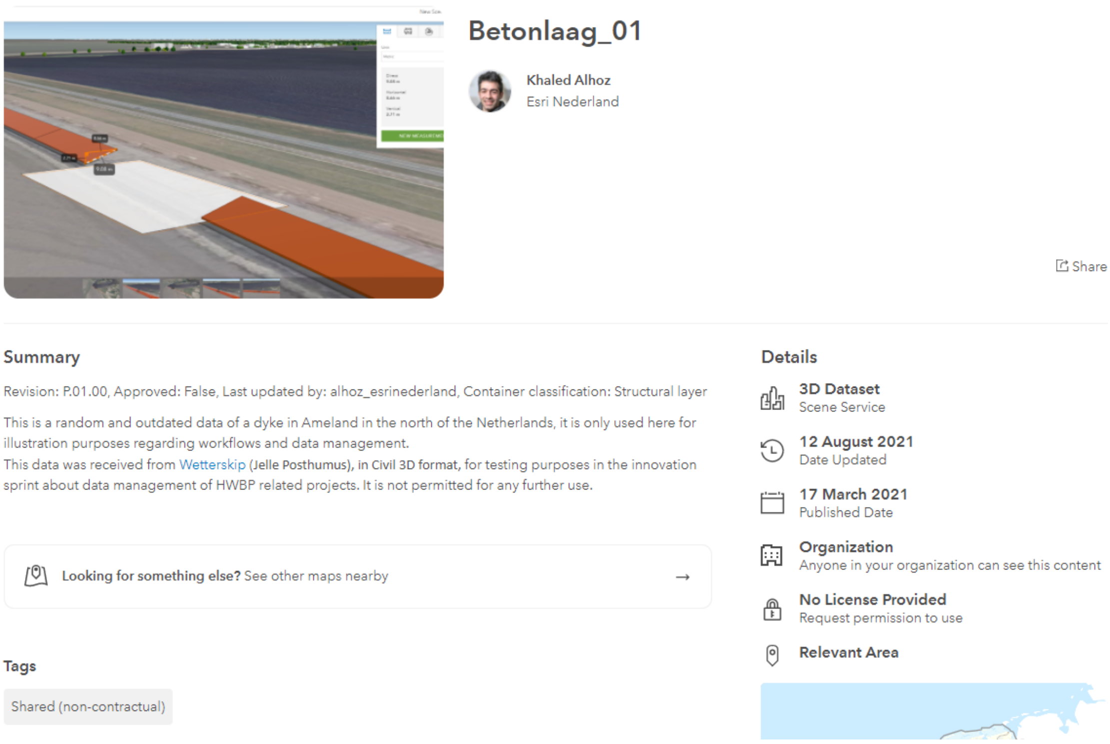
A.3 Self-reflection

During this research, I have learned much about information management, including the application of GIS and BIM data in practice. When starting this project, I had different expectations on the nature of the topic. Whereas I thought knowledge and skills on the technical side were required, the reality was that this topic needs more understanding of the need for a better-controlled information management process. Furthermore, I learned that collaborating in projects adds an extra layer of complexity to information management. Realizing that was the biggest challenge during this research and a very valuable gain. Furthermore, I had to juggle the scientific approach of the research with the need to deploy technology for a practical solution for enabling ISO 19650-1&2:2018. Addressing a topic coming from a market demand would have been easier if scientific rules did not restrict it. From this experience, I have learned more about scientifically approaching a topic than about the topic itself. Even though the research results were not up to expectations, I am pleased to have conducted research that addresses a topic coming from piratical market demand. Besides the gained knowledge and skills, this experience has contributed to my expertise in the field and in the Netherlands as well as to my personal growth. Last but not least, I have learned ArcGIS REST API.

Figures B



(a) All dyke layers converted from the civil 3D model as a single scene layer.

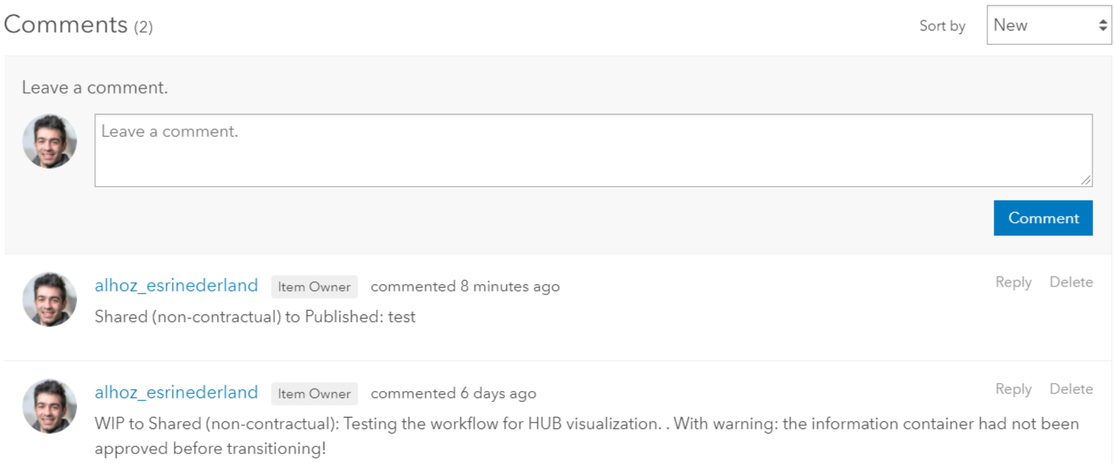


(b) Betonlaag (concrete layer) converted from the civil 3D model as a single scene layer.

Figure B.1: Options for converting the data in Civil 3D format B.1a converting the whole model as a single scene layer vs B.1b converting one semantic layer (concrete layer) as single scene layer

```
{
    total: 2,
    start: 1,
    num: 2,
    nextStart: -1,
  - comments: [
      - {
            id: "4fdb69c632304aee822202e452578018",
            owner: "alhoz_esrinederland",
            created: 1627555373000,
            comment: "WIP to Shared (non-contractual): Testing the workflow for HUB visualization. . With warning: the information container had not been approved before transitioning!",
            parentId: null,
            numReplies: 0,
            latestReply: -1
        },
      - {
            id: "1f84525651a24450929893f476e64b29",
            owner: "alhoz_esrinederland",
            created: 1628067462000,
            comment: "Shared%20%28non-contractual%29%20to%20Published%3A%20test",
            parentId: null,
            numReplies: 0,
            latestReply: -1
        }
    ]
}
```


Rest API JSON response example



UI in ArcGIS Online example

Figure B.2: Example of comments JSON response (upper figure) and UI section (down figure) - Comments (JSON objects) can be used to track down the workflow change of a scene layer item (information container)

+ - View source


```
{
    id: "422af51921c74ad395abeea49fd243a7",
    owner: "alhoz_esrinederland",
    orgId: "emS4w7iyWEQiulAb",
    created: 1615984755000,
    modified: 1628760580000,
    guid: null,
    name: "bk_filterlaag_lijnen3D",
    title: "Betonlaag_01",
    type: "Scene Service",
  - typeKeywords: [
        "3DObject",
        "ArcGIS Server",
        "Data",
        "Metadata",
        "Scene Service",
        "Service",
        "Hosted Service"
    ],
    description: "This is a random and outdated data of a dyke in Ameland in the north of the
    Netherlands, it is only used here for illustration purposes regarding workflows and data management.
    <div>This data was received from <a href='https://www.wetterskipfryslan.nl/' rel='nofollow ugc'
    target='_blank'>Wetterskip</a> (<span style='font-family:Calibri, sans-serif; font-size:11pt;'>Jelle
    Posthumus), in Civil 3D format, </span>for testing purposes in the innovation sprint about data
    management of HWBP related projects. It is not permitted for any further use. </div>",
  - tags: [
        "Shared (non-contractual)"
    ],
    snippet: "Revision: P.01.00, Approved: False, Last updated by: alhoz_esrinederland, Container
    classification: Structural layer",
    thumbnail: "thumbnail/thumbnail1628760577518.png",
    documentation: null,
  - extent: [
      - [
            6.130092024172886,
            53.40130044934073
        ],
      - [
            6.179362788328018,
            53.41508657720291
        ]
    ],
    categories: [ ],
    spatialReference: "28992",
    accessInformation: "",
    licenseInfo: "",
    culture: "en-us",
    properties: null,
    advancedSettings: null,
    url:
    "https://services.arcgis.com/emS4w7iyWEQiulAb/arcgis/rest/services/bk_filterlaag_lijnen3D/SceneServer",
    proxyFilter: null,
    access: "public",
    size: 261460,
    subInfo: 0,
    appCategories: [ ],
    industries: [ ],
    languages: [ ],
    largeThumbnail: null,
    banner: null,
```


guid

https://www.arcgis.com/sharing/rest/content/items/422af51921c74ad395abeea49fd243a7?f=json 1/2

Figure B.3: A Rest API JSON response example of a scene layer item (an information container)

Field analysis & interviews C

C.1 Innovation sprint - information management in the HWBP

In the week of 15-19 March 2021, Esri Nederland organized an event called innovation sprint. The topic of the sprint was *Information Management with a focus on the HWBP*. At the time of finalizing this thesis, an article about this event, available at this link, was written in Esri magazine. The event is a week-long program in which the participants brainstorm innovative ideas to optimize workflows related to the topic of the sprint. Throughout the week, the participants work on realizing these ideas with the technologies available. Stakeholders and parties involved in the HWBP participated in this event and provided valuable input. During the kick-off meeting, the participants, given their roles, identified their needs/challenges. Based on the challenges they face at work, the participants submitted requests as what they would like to achieve at the end of the sprint. These requests were spread over an affinity diagram based on roles/responsibilities (Y axis) and project phase (X axis), see C.1. The following requests were submitted:

- Related to ISO 19650 standards
  - Achterhalen welke data gedeeld wordt en of dat gestandaardiseerd kan
  - Als ingenieursbureau wil ik een uitwisselstandaard voor CAD/GIS zodat ik snel een ontwerp kan converteren, visualiseren en analyseren voor mijn project.
  - Als aannemer wil ik toegang tot de meest actuele en complete data (CAD GIS en etc.) zodat ik tot een weloverwogen en betrouwbare aanbieding kan maken.
  - Als gegevensbeheer wil ik mijn kering in 3d visualiseren zodat ik beter inzicht krijg in de opbouw van de kering en beter aansluit bij de werkelijke kering
  - Hoe kan een waterschap meer met de aangeleverde 3d data?
  - Als gegevensbeheerder wil ik op een eenvoudige manier extra informatie toevoegen zodat ik deze informatie kan gebruiken bij het instant houden van de kering

- Als gegevensbeheer wil ik op een eenvoudige en eenduidige manier de informatie vanuit het HWPB programma opnemen in mijn beheerregister zodat er geen informatie verloren gaat.
- Als gegevensmanager wil ik een eenduidige informatievoorziening dit aansluit op de werkprocessen rondom de werkprocessen rondom de primaire keringen zodat ik de informatie vanuit de verschillende werkprocessen kan hergebruiken.
- als toekomstige beheerder bij WS wil ik dat ik snap waarom een kering is zoals hij is (rekenmodellen, uitkomsten) zodat ik heel veel toekomstige onderzoekstijd kan besparen
- Wat is er al beschikbaar via services voor een projectomgeving?
- Voorbeeld projecten vergelijken, waar zitten de overeenkomsten en waar de verschillen?
- Als informatiemanager wil ik volledige, betrouwbaarder en actuele informatie over de staat van het traject zodat bij aanvang van het project meteen met de goede informatie gewerkt wordt.
- Als projectmedewerker wil ik een duidelijk verschil tussen schetsen en vastgestelde data en dat vooral de vastgestelde data beschikbaar is voor alle betrokkenen.
- Wat is er al aan standaarden? Wat is minimaal? Waar het niet voldoet, wat moet er aangepast worden?
- Op kenmerken data leveren
- Als PD van het HWBP wil ik actuele, gestandaardiseerde data van alle projecten zodat ik overzichtelijk heb wat overal gebeurt en dit met elkaar kan vergelijken.
- Als adviseur ingenieursbureau wil ik vooraf inzicht in de te volgen informatiestandaarden en afgeleide eisen aan ieder door mij uit te werken product zodat ik inzicht heb in de benodigde inrichting van gedeeld kaart-, model- en tekenwerk.
- Als adviseur ingenieursbureau wil ik een dekkend beeld van de bestaande situatie bij start betrokkenheid op een HWBP project. Eenzelfde uitgangspunt op basis beschikbare bronnen, zodat ik lopende het project discussies rond (data)uitgangspunten voorkom of vlot kan duiden.
- Als adviseur ingenieursbureau wil ik onze diverse interne werkomgevingen zelf in kunnen richten op basis van eigen behoeften en (interne)standaarden zodat medewerkers productief en kwalitatief werk kunnen leveren in een bekende omgeving/met set tools onafhankelijk van de keuzen op een individueel project.

- Als waterschap wil ik een standaard samenwerkingsplatform om informatie rondom het project te kunnen delen met de andere stakeholders.
- (middel) Als Informatiemanagement wil ik een gestandaardiseerd platform aan de projectenorganisatie (interne projectorganisatie plus externe betrokkenen zoals ingenieursbureau, aannemers, ...) kunnen aanbieden waarin het projectgebied wordt geduid gepresenteerd (wat ik wel weet en niet weet) zodat ik (informatievoorziening) een goede dienstverlening kan leveren.
- Als ontwerper wil ik graag alle benodigde (ontwerp)gegevens van onze primaire kering makkelijk en overzichtelijk in beeld hebben, zodat er minder tijd en discussie nodig is voor het verzamelen van de meest actuele gegevens.
- Als rayonbeheer wil ik de informatie voorzien rondom de primaire keringen ook meenemen het veld in zodat ik het veld goede keuze kan maken.
- Waterschap/Adviesbureau – initiatie/ verkenning: Als technisch manager van een HWBP project wil ik Inzicht in de technische opgave vanuit de beoordeling van de keringen op kaart. Zodat ik goed weet waar welke technische opgave ligt.
- Als waterschapper wil ik dat alle verzamelde informatie gedurende het project ook beschikbaar is buiten het project.
- Als dijkbeheerder wil ik inzicht in ontwerpbeslissingen zodat ik kan controleren op beheerbaarheid van de toekomstige dijk
- Waterschap/adviesbureau Als omgevingsmanager Wil ik inzicht in stakeholders (perceels-eigenaren), plannen van andere overheden (ruimtelijke plannen, beleid), kabels leidingen, vergunningen. En wil ik per eigenaar op kaart kunnen status kunnen bijhouden. Zodat ik een goed beeld van de omgeving en de knelpunten heb en delen aan anderen betrokkenen.
- Als gegevens beheerder wil ik de revisie gegevens in juiste formaat aangeleverd hebben met de juiste administratieve gegevens, zodat de bestekswijzigingen tijdens het werk ook meegenomen zijn en minder fouten gemaakt kunnen worden. Omdat de gegevensbeheerder niet op het werk aanwezig is en niet van alles op de hoogte is.
- Als omwonende/waterschap/aannemer wil ik up-to-date data zodat ik niet naar verouderde informatie kijk
- (data) Als Informatiemanagement wil ik leunen op gestandaardiseerde afspraken m.b.t. data uitwisselingsformaten (standaard ILS) zodat ik geen verrassingen creëer ten aanzien van de markt.(*daar waar kan gebruik maken opendata) Doelgroepen in de Hub

  - Als aannemer wil ik de opdrachtgever inzicht geven in de status van het beheer en onderhoud zodat de Asset owner/Asset manager zijn rol goed kan vervullen.
  - Als adviseur ingenieursbureau wil ik een dekkend beeld van de bestaande situatie bij start betrokkenheid op een HWBP project. Eenzelfde uitgangspunt op basis beschikbare bronnen, zodat ik lopende het project discussies rond (data)uitgangspunten voorkom of vlot kan duiden.

- Unrelated to ISO 19650 standards
  - Als informatiemanager wil ik dat GISsers en CADders werken op zelfde dataformat zodat geen conversies meer nodig zijn en ik geen vertraging en geen inforamtieverlies ondervindt
  - Als adviseur techniek kennis en innovatie, wil ik graag een evenwichtig beeld van de (innovatieve)projecten in Nederland in de verschillende fases + de kwalificatie van de info, maar ook de witte vlekken (innovatiekansen) om een actueel beeld te hebben van de waterveiligheidsprojecten in Nederland en lopende innovaties. Graag wil ik het verhaal van de dijk zien.
  - Als bestuurder/programmamanager/Interne opdrachtgever/communicatie bij een waterschap Wil ik op kaart eenduidig actueel inzicht in de ligging, fase, planning, projectorganisatie van de HWBP projecten op hoofdlijnen. Zodat ik het overzicht houdt op waar wanneer welk traject wordt gerealiseerd. (op programma management niveau)
  - Als Geoteam binnen het waterschap willen we actuele geoinformatie op een eenduidige manier inzichtelijk maken, zodat dit in verschillende projecten eenvoudiger en sneller kan worden gedeeld
  - Als omwonende wil ik snel en duidelijk kunnen zien wat de plannen zijn zodat ik snap wat voor effect dit op mij heeft
  - Als omwonende wil ik weten wat er in mijn omgeving gaat gebeuren zodat ik weet wanneer ik hinder ga ondervinden

The innovation sprint event was held in Dutch and here is a summary of the outcome in a context related to this thesis:

- Stakeholders who participated in the event come from different parties such as watershapers (waterboards of The Netherlands), Rijkswaterstaat, engineering/construction companies such as Dura Vermeer and Tauw.
- Stakeholders who participated in the event come from different roles such as information managers, designers, contractors, engineers, administration managers, GIS specialists, BIM specialists.

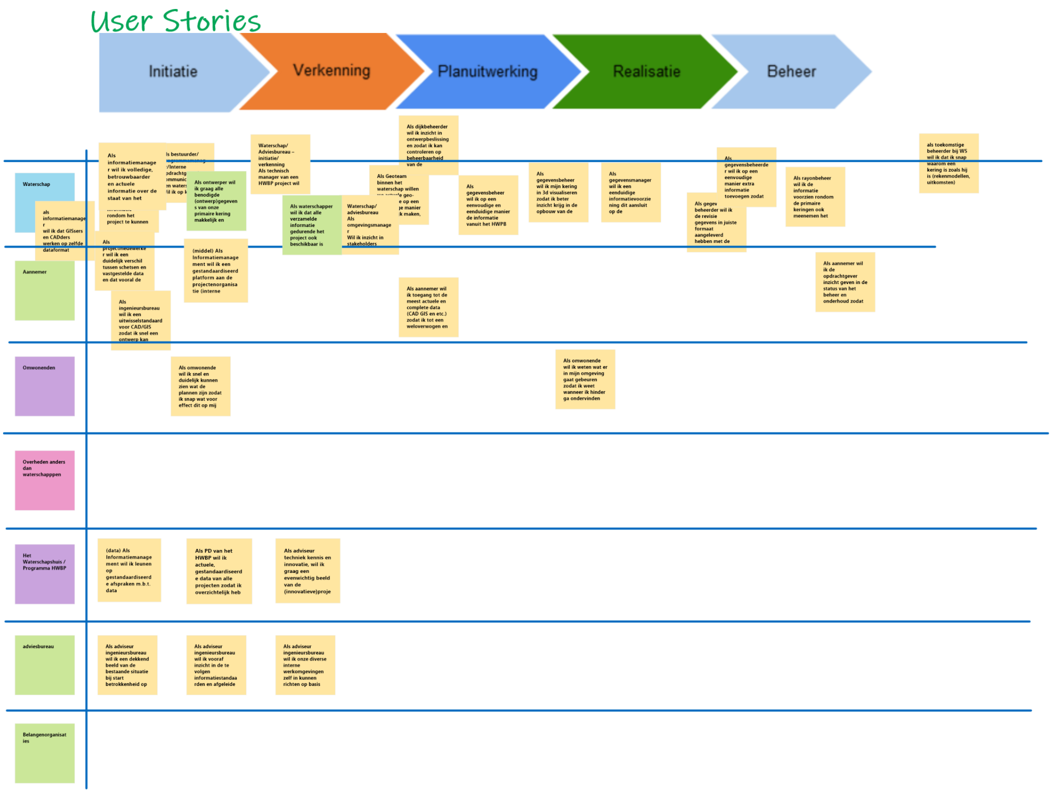


Figure C.1: Affinity diagram - the Kick-off meeting of the innovation sprint of the week 15-19 March 2021

For the purpose of this thesis, the requests of the participants were divided into:

- requests unrelated to ISO 19650 standards (around 20% of the requests)
- requests related to ISO 19650 standards (around 80% of the requests) which are summarized in the following list:
  - Multiple stakeholders - requested standardized way of exchanging information and clear specification for delivering 2D/3D GIS/BIM data (visual information).
  - Designers/engineers - requested easy and reliable access to the most up-to-date data.
  - Contractors - requested a defined source of the reliable and actual up-to-date information/data related to the incident project.
  - Clients - requested having an overview of the progress over the ongoing projects related to the HWBP.
  - Contractors - requested having a clear overview of the specified requirements of the design to avoid wasting time on discussion and looking for information.
  - Contractors - requested the ability to offer the client an overview over an ongoing production of information and project status

C.2 Interviews

Interviews with stakeholders were conducted for understanding workflows and requirements from practice. The aim of the interviews are:

- Investigating what is the practice in terms of the information management standards.
- Identifying the challenges, both practical and technical, in the current practice.
- Understanding the role of Web GIS in infrastructure projects (with focus on HWBP).
- Exploring the amount of interest in ISO 19650-1&2:2018 standards for information management workflow in infrastructure projects.

C.2.1 Questions asked at the interviews

- What is your role/position at your organization? Does it involve (GIS/BIM) data management? And is it project-based?
- What is the role of GIS platforms/software/data at your work/in this story? And is BIM data used on GIS platforms?
- Does the company have projects related to the HWBP?
- Which software/platform are used within the company?
- If there is any, what are the protocols/standards for data managements adopted for projects at your company? does it include standards for GIS/BIM data?
- Is there are any predefined specifications/requirements for the handed-over information (including visual information GIS/BIM) through the phases of a project?
- Have you heard about ISO 19650 standards for information managements in projects/assets life cycle? if yes, would you want it to be adopted at/in your work(flows)?
- Do you have and make a common data environment (CDE - Hub/repository) available for (GIS/BIM)-information/data related to a project?
- How important is managing GIS/BIM data? Do you think that ISO 19650 standards should be adopted for large projects between and within organizations?

The following paragraphs are summaries of the interviews conducted with stakeholders. The way in which the interviews were summarized tried to keep the wording used by the interviewees.

C.2.2 Meeting with V, N - Tauw

V, N is a Product manager BIM at Tauw operate as a data consultant/information management consultant. Sometimes, we have project-based work mainly related to infrastructures like HWBP, or road projects. The role of the GIS platform differs per project, for example, GIS viewer for shared or indoor published information. It helps the information team to have spatial context for doing geo-analysis, (We have a saying at the company *everything starts and end on the map*, so the project closeout with spatially enabled data actually). For some projects, GIS software is not used however the spatial data like point cloud is used in BIM/CAD software (plan 3D, Revit and Civil 3D). Relatics is used as a requirements managing tool or for specified databases. GIS is more interesting in infrastructure projects (such as HWBP projects) where environmental complexity is higher. There are different setups depending on the project requirements, ambitions and goals. Sometimes, the model from BIM software is automatically updated on the GIS platform every other week. Sometimes, we use the two platform in a standalone (independent) work environment. For example, the BIM models are only updated to the GIS platform at the end of a phase.

GIS data provides context to the design, sometimes the model is updated to the GIS platform or GIS data are imported to BIM platforms for technical design level. Sometimes, the model is only delivered as part of the GIS data (in the published state) as this can be a clause in the contract. This is mainly for governmental organization, in this case, the design files (Revit/CAD) do not really leave the company, these files are not really part of the deliverable. Mainly the project requirements define what combination of platforms are used and in which set up. But, sometimes, during the project, smarter decisions are made for this purpose so we adjust the set-up. It is never one environment or one fixed set-up for managing the project information. But even BIM 360 is not entirely aligned with ISO standards. And we are trying to comply with ISO principles but we do not actually fully comply with them. Even within BIM 360 on the technical aspect, it is not fully aligned with ISO standards. Bentley is working on or already is complied with ISO 19650 standards. Autodesk is promising us to fully comply with ISO 19650 standards soon.

Here in Touw, we also have our own internally used standards, and these are different per environment(GIS, BIM or a combination of both). Often, we get the information specification for the deliverable. And we actually want to have these, however, government clients have only requirements for 2D CAD data. So what we do is that we advance the requirements ourselves make them applicable to this new world of 3D CAD and GIS data. This is to guide us through the design process. We do not aim to be ISO 19650 certified. However, some companies, like Sweco, worked with clients who required working with an ISO 19650 certified company. I use ISO 19650 terms like shared information or published information. What I find important is that the process is managed, practically working on a project level and that we have clarity on what information is stored where like incoming information or GIS/CAD data and what is the status of this information. And obviously versioning and other aspects. But it is never one database, for example, some projects are 80% in BIM 360 and 20% is in Relatics environment which does not comply with the idea of ISO 19650 but we use for information requirement management. Different type of alphanumeric data is stored in Relatics to support the design for example meetings conclusion or design information are registered in that environment. We always, for best practice, try to have a clear BIM execution plan that contains project and information requirements. In some case this kind of document is missing so we work according to our standards. It is important that there is a function that helps to manage information. The function that makes sure that everything is delivered in time. But it can also go to having a whole information management team with different roles, GIS specialist or BIM specialist. Usually, the piratical needs drive us to develop information management process/tool. And we use ISO 19650 standards for ideas. As a company, we do not focus on developing a technical tool. We focus on developing standards, process and templates in different setups with the tools we have in the house. Managing data is not only a technical challenge, it is also a process and contractual. These are important aspects on the organizational level. Sometimes there are subcontractors who develop or design different part of the model. For this there are different scenarios, for example, we get an update every week, or only at the end of a phase. This is already a big difference for the project. For this, it is important to manage the process and to come to an agreement. ISO 19650 standards and good practices could help us very well.

Some challenges lie within getting information requirement on the technical level. Often the client delivers a high-level requirement and these should be translated to practical technical requirement. Furthermore, when technology evolves it hard to come to an agreement that deploys this technology for a better workflow. For example, the 3D GIS, we use for underground subsoil. But on a lot of HWBP projects, there is no need or requirement for this. So no clear specification for working with 3D, so it becomes rough.

C.2.3 Meeting with B, M - BAM Infra Nederland

B, M is Programma Manager Digital Construction at BAM Infra Nederland. There are three kinds of certification that you can obtain from .bsi. One for a year, and one for three years that is applicable on projects that include BIM. Now it is a work in progress for .bsi to be able to grant certifications for companies. BAM has been certified for the design and construction process of asset management, however, they are not yet. For some processes, we are still certified according to pas1192-3 (operational phase of construction) and we are working towards transforming this certificate into ISO 19650 (delivery phase of an asset) later this year. We have The Afsluitdijk which is part of HWBP, however, this project is with the Rijkswaterstaat. Besides the protection from the sea, the work on the Afsluitdijk includes pumping the water from the riverside to the sea. The biggest change is that we come from a document-based process and not from an information data-based process. So, we mainly see the difference in ISO 19650 and the other ISO 9001. For example, in the document-based processes we hand in CAD drawings and not in data. What we see is that lots of companies ask us to deliver 2D CAD files and these are more drawings than data (it is not very smart data). And our client puts them in GIS systems then add all kind of metadata to it.

That's the change that the ISO 19650 came far with. So, at the start of the project, the client defines what kind of information or data they want to have and not what kind of document (drawings). Data means is not only geometrical data but all kind of structured, not geometrical data that comes with it (attributes). Kadaster, for example, each object in their GIS has a unique number that refers to information in the database (e.g. owner and the value of properties). So the goal would be that when clicking on an object, you get the geometrical drawings with these structures non-geometrical data on one (*.pdf) document. This is how it should be, for example, the Rijkswaterstaat has so-called ILS (information delivery specification) which describes what metadata they want to have with the geometrical data in the delivery. The best example of this process is kernGIS which is the GIS database Rijkswaterstaat use for their asset management work. An example of work we do is pavements, for that they do not only want the geometrical situation of it (where it is) but also what kind of materials were used and the date when it was placed. This information is required for future maintenance work in 5 or 10 years. This allows them to ask the system when they have questions about their pavements. We use GIS for many years already, I mean, the delivered products are in GIS readable formats. Around 10 years ago, the companies started to ask for deliverable's to be stored in their GIS system which was the reason why BAM started using GIS as well. At the end of the project, we should deliver GIS data (for Kern GIS) and they set requirements on how the data should be delivered.

In the construction phase we use BIM software Autodesk mainly and Bentley and sometimes some metadata. But it is really hard to convert and store this data directly in Kern GIS because it is a 2D database and has a different object structure. Therefore, manual work is always required. They use 2D data for 10 years now, and they are searching on what to do with 3D BIM models. That's why they don't ask for the 3D data we have to be used in the maintenance phase ISO 19650 is part of the solution, it is a process to help get data delivered as required. But it does not guide on how to structure the data.

It is good that Esri is researching how their system can be applied for the CDE solution complied with ISO standards. Therefore, you need a controlled data environment. The version is very important and part of the ISO 19650, so you can see if you have the latest version of the data set. And the approval process is important, *where is the data stored? and how can it be shared(in shared status?* these things are missing in the GIS system. Most important is finding a way to give the user the ability to check if the version at hand is the last up to date version (approved shared and status), e.g. if they are on the construction site or somewhere else on their IPad, and they are checking a file or a GIS item. Especially to be able to see that the client has approved the asset. It can be very difficult, but a very easy step (this was our first step) was just using folders for *WIP, shared, published*. The second step we did was having the metadata in a column where you see the status so the versioning method is pushing away (to the archive) the older version and only keep the usable ones. Versioning and the status are important and also the suitability status (what for the data can be used) is also very important. These are specified in the ISO document.

For example, it is suitable for calculation, construction or maybe only for a rough sketch with the client. So if these three can be made available by Esri, the process according to ISO standards is then possible. The rest of the things are in the process such as the standards and object code, these things differ per company and projects. The CDE is not one system, there are many systems but each handles a different kind of data. There is Relatics system for structured non-geographical data to put the requirements of the client, SharePoint for the documents and BIM360 for BIM models. So, the easier the system can provide the functionalities for ISO standards the easier it can be engaged in the ISO solution as CDE. In our implementation of ISO 19650's CDE, BIM360 and SharePoint are involved and this year! We are planning to add the GIS system to it. It is already possible actually, but there are lots of manual work that depends on people. For example, for versioning, a person does the save as and delete the item and replace it with the new one. From our GIS team, I heard that the challenge now is in the versioning where lots of manual work is required. We are at the start now, so we don't know if it is achievable at the moment are we postpone the work until an update from esri. The idea is GIS is our main system for asset management projects. So we use only GIS in these projects and BIM software are not involved. So, as we asked the BIM modeller how do you keep a version of the model and how do you see if you have the latest version, and we ask the same for the GIS employees. At the moment these processes are supported in BIM for a file, so we only can say that this file is the latest file. But it would be a huge achievement if the process can support this for objects within the drawings.

You must know that, in huge projects such as the Afsluitdijk, so it is chunked into small pieces with all kinds of something that is already finalized and something has to start still. So we have a big coordination model with the models in it. So we chunk it into files to get them into the workflow of WIP shared published. So the Afsluitdijk is a couple of hundred models that altogether stitched in a coordination model. Probably it is easier to do it in a GIS system that the workflow goes for an object and not for a whole model. There is a lot of discussion about the naming conventions, so you should have one, but my opinion is that it should be left open. Here we have our own, so we used naming conventions that used to have on drawings in the past. So we adhere to the principle but not the British one. The naming conventions in the British national annexe can be good to show an example but if it is only based on that, then it is limited, If the client can configure their own, then they can easily integrate GIS with other systems they have such as SharePoint. Most of the time, what a container is (in terms of what data each container has) depends on the contract. So, sometimes we use geographical structure: this means that the model is divided per few km, for example, the Afsluitdijk is very long, this means that every container has all discipline but with few km. So nothing is fixed, also in the same project (Afsluitdijk) the road is one container. Because it is one objects whereas, for the pumps, each pump is one container and the lock of pumps is one container. This can be seen as a project within a project. So really everything depends on the planning, logistics and what kind of infrastructure you have. In practice, some things are discussed within the teams for the information workflow. It is hard to get all functionalities that comply 100% with ISO 19650 standards. What important is that the process of ISO 19650 is clear to parties involved.

Bibliography

N. Aalbersberg. BIM & GIS dichter bij elkaar - IFC-Data in ArcGIS. *esri-magazine*, 2021. URL https://magazine.esri.nl/esri-magazine-2-2021/ifc-in-arcgis-pro/. Url date: 2021-07-16.

BS EN ISO 19650-1 - Concepts and principles. Organization and digitization of information about buildings and civil engineering works, including building information modelling (bim) - information management using building information modelling, 2018. URL https://www.iso.org/standard/68078.html. Url date: 2021-03-08.

BS EN ISO 19650-2 - Delivery phase of the assets. Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Information management using building information modelling, 2018. URL https://www.iso.org/standard/68080.html. Url date: 2021-03-08.

A. Kemp. Guidance Part 1: Concepts. In D. Churcher, S. Davidson, and A. Kemp, editors, *Information management according to BS EN ISO 19650*. The UK BIM Alliance, CDBB, and bsi., 2019. URL https://www.ukbimalliance.org/wp-content/uploads/2019/04/Information-Management-according-to-BS-EN-ISO-19650_-Guidance-Part-1_Concepts_2ndEdition.pdf.

A. Kemp. Guidance Part C Facilitating the common dataenvironment (workflow andtechnical solutions). In *Information management according to BS EN ISO 19650*. UKBIMFramework - The UK BIM Alliance, CDBB, and bsi., 2020. URL https://www.ukbimframework.org/wp-content/uploads/2021/02/Guidance-Part-C_Facilitating-the-common-data-environment-workflow-and-technical-solutions_Edition-1.pdf.

A. Kemp. Guidance Part 2: Parties, teams and processes for the delivery phase ofthe assets. In D. Churcher, S. Davidson, and A. Kemp, editors, *Information management according to BS EN ISO 19650*. UKBIMFramework - The UK BIM Alliance, CDBB, and bsi., 2021. URL https://www.ukbimframework.org/wp-content/uploads/2021/02/Guidance-Part-2_Parties-teams-and-processes-for-the-delivery-phase-of-assets_Edition-6.pdf.

Z. Ma and Y. Ren. Integrated application of BIM and GIS: An overview. *Procedia Engineering*, 196:1072–1079, 2017. doi: 10.1016/j.proeng.2017.08.064.

K. Oberste-Ufer. Expert View: How ISO-19650 Will Change the Construction Supply Industry. Online website, 2019. URL https://blog.dormakaba.com/expert-view-how-iso-19650-will-change-the-construction-supply-industry/. Url date: 2021-05-10.

J. Pánek and J. Burian. Online visualisation. In *Spationomy*, pages 221–231. Springer International Publishing, nov 2019. doi: 10.1007/978-3-030-26626-4_10.

N. praktijkrechtlijn. SIST-TP CEN/TR 17439:2020 - Guidance on how to implement EN ISO 19650-1 and -2 in Europe, 2020. URL https://standards.iteh.ai/catalog/standards/cen/472dfc81-5589-413a-b646-4132e376ca07/cen-tr-17439-2020. Url date: 2021-05-11.

S. A. F. S. A. Rahman and K. N. A. Maulud. Approaching BIM-GIS integration for 3d evacuation planning requirement using multipatch geometry data format. *IOP Conference Series: Earth and Environmental Science*, 385:012033, nov 2019. doi: 10.1088/1755-1315/385/1/012033.

R. Roberts. Update hosted scene layers using replace layer. Web page article, 2020. URL https://www.esri.com/arcgis-blog/products/arcgis-online/data-management/update-hosted-scene-layers-using-replace-layer/. URL date: 2021-07-16.

K. Rudden. BIM and ISO 19650 from a project management perspective. PDF slides, 2019. URL https://www.frinet.dk/media/1307/381783_efca_flipbook_bim_fri.pdf. Url date: 2021-03-08.

P. Shillcock. From BS 1192 to ISO 19650 and everything in between. Website, 2021. URL https://www.thenbs.com/knowledge/from-bs-1192-to-iso-19650-and-everything-in-between. Url date: 2021-05-16.

P. Shillcock and M. Suchocki. Implementing BIM 360 Docs to Support the New ISO 19650 Series of Standards Using BIM. YouTube, 2019. URL https://www.autodesk.com/autodesk-university/class/Implementing-BIM-360-Docs-Support-New-ISO-19650-Series-Standards-Using-BIM-2019. Url date: 2021-03-08.

G. Spencer. Using BIM 360 Docs as a CDE Aligning to ISO 19650. YouTube, 2019. URL https://www.youtube.com/watch?v=7NMDNUa_X5A. Url date: 2021-03-08.

SymetriUK. ISO 19650 Naming & Workflows Explained. YouTube video, 2020. URL https://www.youtube.com/watch?app=desktop&v=lEvarrG6w5g. Url date: 2021-05-05.

Colophon

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