Computational Support for Tunneling Activities: A Case Study in the Construction of the New Subway System of Santiago, Chile

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ABSTRACT

Technology implementation has become crucial to reduce costs and diminish errors in construction projects. In massive projects such as tunneling construction, computational modeling can be useful for several planning, execution and control activities during the lifecycle of the project. An analysis of the building requirements was done in a particular case study with the aim of evaluating how the current computational schemas support tunneling activities during the construction phase. Then, these requirements were compared with the model view definitions (MVD) used by the industry foundation classes version 4 (IFC4) from BuildingSmart. Finally, based on this comparison, an assessment on how ifc4 supports tunneling activities was performed.

The construction of the new subway station "Estacion Ñuñoa" (one of the new ten stations of the subway system of Santiago, Chile), was used as the case study. Its building requirements, specifications and tasks were gathered and studied. Since excavation and structural support of the tunnel represent the largest investment of the project the analysis was performed on these tasks. This study summarizes the information requirements of these tasks and whether or not they are supported by the ifc4. Based on our findings, a proposal to include the not-supported information requirements in the current ifc4 schema is presented.

Keywords –

IFC, information exchanges, tunnel modeling, tunnel excavation

1 Introduction

Due to the increasing transportation needs in the world, tunneling construction has become very important to overcome transportation loads. Particularly in growing cities where subways are a transportation mean and new routes are planned and constructed year after year.

Because of the amount of people that subways transports, safety and quality of construction of underground tunnels become a relevant issue. These issues are important not only to construction companies, but also for governments and agencies, which make recommendations and specifications for construction. These requirements are the starting point to develop new technologies to support tunneling construction.

Within the last years, software used for sharing project information have become mandatory in this type of construction. Few years ago it started with simple 2D CAD but nowadays 3D is the minimum standard. With the addition of time and Gantt charts to the models, benefits such as planning gains and cost reductions have been achieved. But the creation of the models is not exempt of difficulties since interoperability issues arise when models are developed in different software platforms and shared among the stakeholders.

According to a 2004 NIST report, enormous losses are generated in the construction industry because of lack of interoperability. They reported that this issue annually leads to US$15.8 billion of losses in the US construction industry [1].

In order to overcome the interoperability issues, standardization approaches such as the standard for exchange of product model data (STEP), the AP225 building elements using explicit shape representation (ISO 10303-225:1999), the industry foundation classes (IFC) or Construction Operations Building Information Exchange (COBie) have been developed [2].

In this research our team focused on the IFC effort maintained by BuildingSmart which is one of the most used by software based on BIM [2]. Throughout the research and study of the specifications and reports of the construction of one of the new subway station in Santiago, Chile the team assessed how the current IFC schema supports tunneling construction. While some entities and required features do exist in the current schema, some of them where not found and will be proposed as new IFC entities.

This research is based on previous studies done in this area and seeks to generate knowledge that can facilitate interoperability and computational modelling of subway tunnel construction.

2 State of the art

2.1 The IFC schema

The IFC approach was created in 1994 by BuildingSmart aiming to support construction requirements in the construction industry. IFC is a standardized schema that targets the definition of construction information in computer supported environment. It defines object-orient Model View Definitions (MVD) that create reference models with unidirectional relations that facilitate the information definition of construction objects. The latest release of the schema is the IFC version 4 (IFC4) [2].

Due to its interoperability focus among different software, some governments such as the Danish government have established the mandatory use of IFC in construction projects. Others go even further as the Finish or Norwegian governments that require BIM and IFC as a must in new construction projects [3], [4].

2.2 Previous researches

Authors as the Japanese engineer Yabuki have study tunnel construction and its incorporation into IFC. His last publications are focused on design, construction and maintenance of tunnels [5], [6]. But these publications are dedicated only to tunnels constructed in Japan, where shielded tunnels with tunnel bored methods are the main construction method used. In this technique, the tunnel is excavated and a tunnel boring machine is used to excavate and then, using hydraulic jacks, rings with layers of steel and concrete are placed between the soil and the tunnel shield [5], which is different from the tunnel construction method used in Chile.

The excavation-construction method used in Chile for tunnels is the NATM or Austrian method that involves excavation with traditional excavation machinery and in-situ built shields made with concrete and steel reinforcements [7]. More details about this method are provided later in this paper.

In another study developed by a German research team [8], an improvement to the Yabuki' study was proposed. They proposed a generalized alignment model based on IFC4 to describe infrastructure project as highways, bridges or tunnels. This model is basically a defined set of the construction activity requirements that allows a standardization of the construction procedures [9].

As we noticed during our research, Yabuki's findings have not been added to the current IFC version yet.

3 Excavation methods

Data and information about the excavation and construction was gathered from reports and specifications of the construction of a station of one of the new subway lines in Santiago, Chile, specifically Ñuñoa station from Line 6. This new line is 15,3 km long and will have 10 stations that will benefit around 870,000 people [10].

From all the construction items specified for the station, only two where studied in detail: excavation and tunnel support. They were chosen because of their importance in the tunnel construction costs [11].

Looking at the gathered data it is noticeable that the construction method traditionally used in subway construction in Chile changed for this subway expansion. The previous used method was the side drift method that consists in dividing the excavation cross-section area into 5 areas as it is shown in Figure 1. This method allowed the excavation of big cross-section areas but with low productivity, since the size of the sections make difficult the utilization of traditional excavation machinery. The daily average progress of this method is between 0.3 to 0.6 linear meters [7].

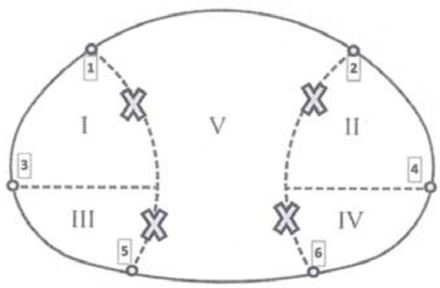

Figure 1. Side drift tunnel construction method [7].

Moreover, this construction method has the following costs and operation issues:

1. It needs 6 lining joints between the excavated areas as it is shown in Figure 1.
2. Two vertical walls need to be constructed and then demolished to support the excavated areas.
3. The tunnel section is stable as a whole only when all the five sections are completely excavated.
4. It causes surface subsidence above the constructed tunnel as it is shown in Figure 2.

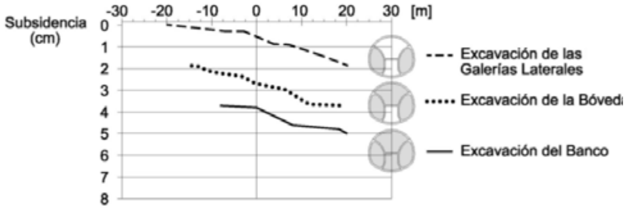

Figure 2. Surface subsidence above the constructed tunnel [7]

In order to avoid the stated construction issues, the company in charge of the excavation proposed another construction method called auto-supporting vault. This method produces less surface subsidence and it divides the excavation cross-section area only into 3 sections instead of 4: vault, bank and against-vault area [7].

As it can be appreciated in Figure 3, the vault construction is composed by: primary vault lining, 2 beams in the vault base and outside the tunnel area, and a second vault lining.

Figure 3. Auto-supporting vault method schema [7]

The beams are 12 meters long micro-piles divided in 2 pieces: a 3 meters long PVC segment and a 9 meters long steel segment.

Due to the size of the station, the construction of the vault section has been divided into 2 phases as it can be appreciated in Figure 4.

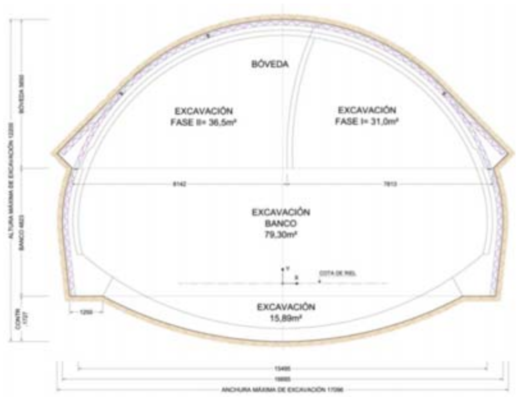

Figure 4. Detail of construction phases of the vault [7]

The benefits of this technique can be summarized as follows [7]:

- Beams eliminate the over-excavation risk that can affect the surface above the tunnel.
- The two-phase excavation allows the utilization of automatized concrete application, which is significantly better than manual concrete application because of its time and resource efficiency.
- The construction of the auto-supporting vault guarantees soil stability.

4 Structural support

In this subway construction, the procedures and requirements used for tunneling support meet the Chilean regulation for reinforced concrete (Nch 430 of 2008) and the US code for structural concrete (ACI 318-05). Based on these requirements a process model stating the information needs can be created:

4.1 Requirements for first lining layer

- 5 centimeters thick pumped H-35 concrete
- First electro-welded steel mesh
- Reticulated frame type 115.32-25 on the perimeter and type 70.28-22 on the temporary plane at 1 meter from the axis.
- 20 centimeters thick pumped H-35 concrete on the vault and 13 centimeters thick on the temporary wall
- Second electro-welded steel mesh
- 15 centimeters thick pumped H-35 concrete

4.2 Requirements for the second lining layer

- Reinforcement of the steel frame on the foundations of the first lining layer of the vault.
- Steel corrugated frame.
- 20 centimeters thick pumped H-35 concrete

5 Model View Definitions

With all the gathered information, MVDs are defined based on the information exchanges needed for the activities related to excavation and structural support of tunnels. These MVD are a proposal of how they shall be added to IFC4 based on Yabuki's studies.

Yabuki's proposal for IFC_tunnel [5], is taken as the basis because it proposes the MVD for the first stages of tunneling construction which is appropriate for this study. Based on his proposal, the research team suggests the creation of an entity named "IFC_Excavation" that has to be part of IfcCavern which is a section of IFC_tunnel. A diagram of where the entity has to be added in the IFC_tunnel is shown in Figure 5.

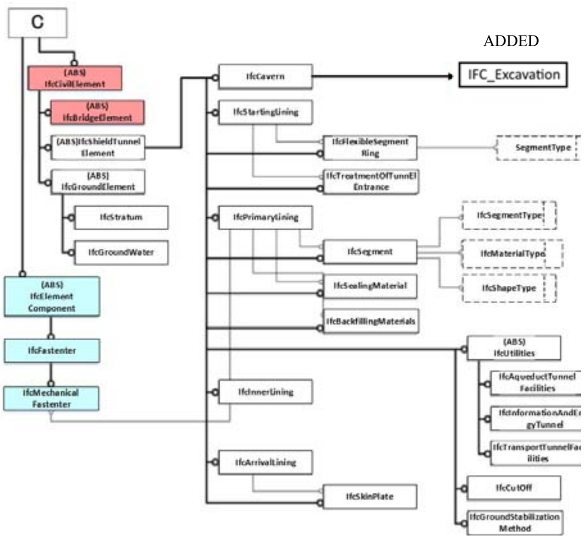

Figure 5. Addition of IFC_Excavation into IFC_tunnel (the schema is taken from [5] where C indicates the IFC_tunnel and IFC_Excavation is proposed in this research)

Furthermore, the MVD proposed for IFC_Excavation with its corresponding means and information requirements is shown in Figure 6.

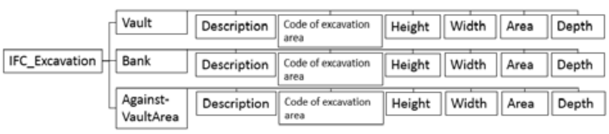

Figure 6. MVD proposed for IFC_Excavation

Finally, as shown in Figure 7, the MVD proposed for the structural support of the tunnel (IFC_StructuralSupport) is also added to the proposed IFC_tunnel suggested by Yabuki, specifically on IfcShieldtunnel since it address tunnel shielding protection.

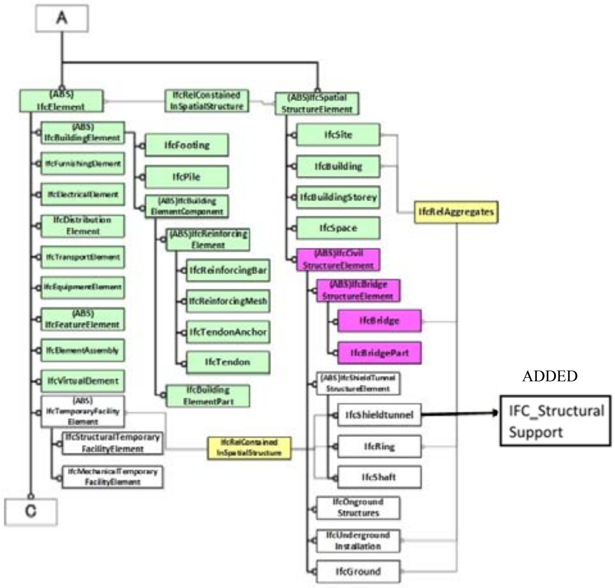

Figure 7. Addition of IFC_StructuralSupport into IFC_tunnel (the schema is taken from [5] where A indicates the IFC_tunnel and IFC_StructuralSupport is proposed in this research)

The means and information requirements for IFC_StructuralSupport are addressed by existing IFC4 entities. Only their association is shown in figure 8.

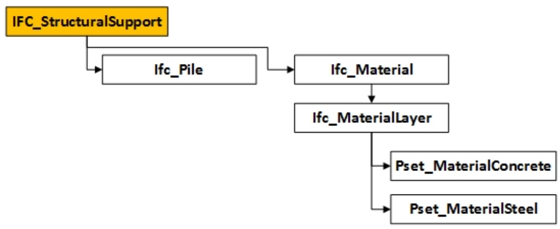

Figure 8. Associations of IFC_StructuralSupport with existing IFC4 entities.

6 Information requirements needed in IFC4

To compare the information requirements for tunnel construction with IFC4, the activities will be divided in two groups: excavation and structural support of it. Both of them do not explicitly exist in the IFC4, but the latter has been studied and proposed by Yabuki [5], [6]. Analyzing the information exchanges needed for excavation, the following information exchanges with its corresponding type of parameter shall be added to IFC4 to complement Yabuki's studies and support tunneling computational modeling (see table 1):

Table 1. Information exchanges needed in IFC4 to represent excavation activities

Activities related to	Information needed	Code
Vault	Description	String
	Code of excavation area	Integer
	Height	Integer
	Width	Integer
	Area	Integer
	Depth	Integer
Bank	Description	String
	Code of excavation area	Integer
	Height	Integer
	Width	Integer
	Area	Integer
	Depth	Integer
Against-Vault area	Description	String
	Code of excavation area	Integer
	Height	Integer
	Width	Integer
	Area	Integer
	Depth	Integer

The information requirements needed to represent the structural support of the tunnel in IFC4 are summarized in Table 2. Likewise Table 3 summarizes the information exchanges needed for the activities related to the beams. Additionally a column was added to Tables 2 and 3 to show whether the existing parameter in IFC is needed in this project or not.

Table 2. Information exchanges needed for structural support found in IFC4 [12]

Construction element	**Description**	**Parameters**	**Inherited from**	**Comments**
Pumped concrete	Material	CompressiveStrength MaxAggregateSize AdmixturesDescription Workability WaterImpermeability ProtectivePoreRatio	Pset_MaterialConcrete	These parameters are required by the project, except ProtectivePoreRatio
- electro-welded steel mesh - reticulated frame	Material	YieldStress UltimateStress UltimateStrain HardeningModule ProportionalStress PlasticStrain Relaxations	Pset_materialsteel	All of these parameters are required by the project
- Pumped concrete - electro-welded steel mesh - reticulated frame	Thickness	Material LayerThickness Name Description IsVentilated Category ToMaterialLayerSet	Ifc_Materiallayer	These parameters are required by the project, except IsVentilated and Category

Table 3. Information exchanges needed for beams found in IFC4 [12]

Construction element	**Pset_Pile**	**Parameters**	**Comments**
Beams	Pset_concreteElementgeneral Pset_precastconcreteelementfabrication Pset_Precastconcreteelementgeneral		Not required in the project since steel beams are specified
	Pset_Pilecommon	Reference Status	These parameters are required by the project
	Pset_condition	AssessmentDate AssessmentCondition AssessmentDescription	
	Pset_environmentalimpactindicators Pset_environmentalimpactvalues Pset_manufactureoccurrence Pset_Manufacturertypeinformation Pset_Packinginstructions Pset_servicelife Pset_warranty		These parameters are not required by project specifications

7 Conclusions

Analyzing the different construction methods used around the world to build tunnels, it is noticeable that several construction procedures, requirements and technologies are used. While Japan uses tunnel bored method to excavate and rings to build the tunnels, Chile still uses traditional excavation method with manual lining installation.

Focusing on the information exchanges it is clear that still different construction elements needs to be studied to overcome the interoperability needs of computational modeling. In this particular study, the information exchanges for excavation and structural support of a tunnel where studied finding that while some elements are supported on the current version of IFC, some of them still need to be added to be able to support all tunnel activities.

Finally, it is also important to notice that some governments have taken into account the importance of IFC to address interoperability issues. This kind of examples should be explored in more detail to propose policies to overcome interoperability losses in other places around the world.

8 Perspectives

It is important to keep studying and updating the information exchanges supported by IFC because the lack of support of construction elements with particular characteristics and means will keep causing interoperability losses. In this particular study only excavation and structural support of tunnels were studied, but still there are other tasks that need to be studied in order to propose interoperability and modeling solutions and reduce interoperability losses.

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