Dipartimento di Architettura Urbanistica Ingegneria delle Costruzioni

Course of Building and Architectural Engineering

Integrating BIM with Earthwork New Technology and Processes

Machine guidance, IFC 4.3, Dynamo and technologies for an interoperable future

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"The intention is to reflect that BIM is not a thing or a type of software but a human activity that ultimately will involve broad process changes in construction" [3]

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English Abstract

Earthwork processes take part at the very beginning of a building construction phase, if not well designed and controlled, they may cause time delays or variations in the estimation of costs. After the introduction of new technologies into heavy earthwork machinery, such as GNSS/RTK, the amount of data that can be collected during the working process has increased exponentially. BIM approach is now becoming more and more present in every project by mainly focusing on the stages after the earth movement phase, keeping the geometric/parametric modelling of the topographical surface and processes with less details. To keep track of the excavation process it is important to have constant information about the current morphology of the topographical surface, the volumes of material moved and consequently time and money spent to achieve the "as project" situation. So, the need of a new approach on data management is required. In first place is necessary to define the volume of earth moved, thus, Hand-Rovers, UAV and laser scanning (Lidar) are studied to define efficient and cost-effective ways to retrieve the actual state of the site before and during earthworks. While, for obtaining the current model of the site during the excavation, it is proposed a new usage of a Dynamo script for model updating.. Existing BIM oriented tool are instead studied and proposed to manage the information during construction and design in order to fulfil the scope of the process proposed. The aim of this thesis is to analyse the existing methods, technologies and tools that the engineer has at its disposition, and to define a link within the BIM, GIS and spreadsheet handler software (or database). With the final aim of helping the project manager to keep a well-defined and updated model that can returns useful data for developing reports and checks of the "as built" conditions. Main concerns of this study is to experiment the creation of a reliable Digital Terrain model (DTM) using initial surveys and machine mapped points by keeping track of the information related to the productivity of the machinery. To enhance the management of the information and to ensure interoperability among disciplines an IFC schema and its property sets should be assigned to task and to the modelled terrain. It will be used parametric software such as Dynamo within Revit environment and for the case study it is considered Trimble platforms linked to new CAT excavator. The method required to retrieve the useful information on site experiences and via a literary review. The proposed solution had to face with real condition of a working site that is subjected to variations and imprecision due to system malfunction or workers imprecisions.

Italian Abstract

I processi del movimento terra prendono parte, in maggior quantità, all'inizio della fase di costruzione. Qualora tali processi non siano ben progettati e controllati potrebbero causare ritardi o variazioni dei costi rispetto a quanto estimato. Conseguentemente all'introduzione di nuove tecnologie all'interno dei mezzi di movimento terra, ad esempio GNSS/RTK, la mole di dati che può essere raccolta durante la fase operativa del mezzo è incrementata esponenzialmente. L'approccio BIM sta diventato sempre più presente tra i vari progetti, purtroppo però concentrandosi su altre discipline invece che sul movimento terra, lasciando così la modellazione geometrico/parametrica della superficie topografica e dei processi con meno dettagli. Per tener traccia del processo di scavo è importante avere un flusso di informazioni costante riguardo all'attuale morfologia della superficie topografica, del volume di materiale mosso e conseguentemente del tempo e costo per ottenere lo stato di fatto corrente e, infine, quello di progetto. Dunque, un nuovo approccio sulla gestione dei dati è necessario. Per prima cosa è necessario definire il volume di terra mosso, così, rovers, UAV e laser scan (LiDAR) vengono studiati per poter definire quale sia il più efficiente per ottenere le condizioni iniziali del sito prima di iniziare il processo di movimento terra. Mentre per ottenere il modello le condizioni dello stato di fatto durante la fase di lavorazione, viene proposto una nuova applicazione di Dynamo come generatore automatico della superficie topografica. Strumenti BIM esistenti sono invece studiati e proposti come soluzioni utili alla completa riuscita del processo proposto. L'obbiettivo della presente tesi è quello di analizzare i metodi, tecnologie e utensili che gli ingegneri hanno a loro disposizione, e quello di definire un "link" tra BIM, GIS e i programmi che gestiscono fogli di calcolo (o database). Con scopo finale quello di aiutare il project manager a tenere un modello ben definito e aggiornato che possa restituire dati utili per la produzione di documenti e report per il controllo generale dello stato di avanzamento lavori. Tra le attività principali di tale tesi vi è lo sviluppo e la sperimentazione della creazione di un modello digitale del terreno (DTM) affidabile utilizzando ispezioni iniziali e punti mappati tramite i macchinari tenendo comunque traccia delle informazioni relative la produttività dei mezzi utilizzati. Per incrementare la gestione e assicurare l'interoperabilità tra le discipline uno schema IFC e le relative property set devono essere assegnate al modello del terreno e le attività programmate. Tra gli strumenti utilizzati vediamo l'utilizzo del software parametrico Dynamo in ambiente Revit e per il caso studio vi sono le piattaforme Trimble legate ai nuovi escavatori CAT. La soluzione proposta, inoltre, deve comunque interfacciarsi con le reali condizioni di un cantiere in quanto soggetto a imprecisioni per via di malfunzionamenti di sistemi o errori umani.

1 Introduction

In the history of the AEC industry the term BIM is coined by Professor Charles M. Eastman in the 1970 and it means the computerized modelling of a generic building construction [1]. Then, Building Information Modelling was applied in 1987 with the aid of a virtual building of ArchiCAD by Graphisoft and has been widely spread within a publication from Jerry Laiserin in the USA in 2002. Designing with a BIM approach means more than creating a 3D model, it means creating a complete representation of a building process defining parameters, geometries, calculations and relationship between the modelled elements. Using the BIM approach means also having a model of the construction that can be standardized and shared with all the figures involved, giving the possibility to work remotely on the same file from different positions. To achieve these benefits is important to use a common language and modalities of approach among stakeholders and consequently the requirement of interoperability becomes fundamental. Among the benefits and aims of the BIM approach there is the possibility to automize the production of documents and checks using the BIM model itself. Currently, this modelling method is mainly used for processes related to the design of the building itself while for earthworks has been usually neglected.

Earthwork is a major part of many construction engineering projects and considered a key indicator of the project outcome [64]. This technology called machine guidance born int the 1990s, thanks to the development of automatic total stations and global positioning system the integration of surveying and machine controls at construction site became reality [61]. The measuring and guidance system used in the early 2000 have been based on laser and ultrasonic technology and already allowed tighter tolerances and better smoothness for the surface, a reduction in manpower and an increase in productivity [63]. At the early stages of the 3D machine guidance system with GNSS, it was already clear that such technology could have increased the productivity avoiding reworks, ensuring accuracy and avoiding the presence of grade checking (increasing thus the overall safety of the process), but in the beginning it was required line of sight of the total station and GPS signal [62]. The continuous upgrade of the logical processor of the instruments allows the creation of more detailed 3D DTM and the possibility of georeferencing the machine by means of VRS (Virtual Reference Station) eliminating so the presence of the total station. Within recent years the earthworks heavy machinery has been upgraded with built-in systems that allow the collection of data during the working time thanks to GNSS (Global Navigation Satellite System) and RTK (Real Time Kinetic) monitoring systems and with the help of IMU (Inertial Measurement Units) applied directly on the machine components [67]. The amount of information that we can collect from a specific

equipment has increased exponentially. During the design phase is important to prepare the model to receive and elaborate the data to simplify the controls of the "as built" condition by returning numerical and visual information to the project manager.

The main challenge of the earthwork field is to measure with good precision (e.g., error in volume calculations not exceeding 5%) the equipment productivity and usage. It is required accurate excavated soil quantities reports as these are used for compensating contractors and subcontractors under certain procurement arrangements such as the "cost-plus", meaning that the contractor is charged for the volume of work completed as the process proceeds. The more the project is complex the more the bill of quantities is likely to be under or over estimated.

While speaking about earthworks projects design is important to define the GIS (Geographical Information System), which is an information system dedicated to the association of data with their exact geographical position. It will be then discussed one of the most important schemas, which is CityGML, and its possible integration with the information carried by the BIM approach.

1.1 Scope

The interested into this study is given by the opportunity of studying the BIM integration of the earthworks and the machine guidance system during their initial stages of development.

Scope of this thesis is to study the current situation of the whole excavation process and the tools and approach used. Fundamental will be the study of the BIM approach and its possible integration withing the design, management and executive phase of the work. The suggested solution aims to increase the overall efficiency, to ease the control of the "as built" and the exchange of information. Processed and collected data during the control of the work in progress are useful to produce bill of quantities, payments to subcontractors, store data for future precise time/cost estimations and continuous checks of the process quality.

We can then summarize in the list below the problem studied:

- Enhance the exchange of data coming from the designer of the earthworks and the other actors (Using BIM-GIS approach)
- Propose IFC schema that can be suitable to transfer the information produced in the three phases of the process.
- Identify a solution or a usage of the machine guidance technology mapped surface to avoid survey in situ.

- Enhance productivity and ensure safety using site SBS and WBS.

To fulfil the purpose of the thesis it will be examined in deep the BIM-GIS approach, the actual technology of the machinery, the software existing on the market and the procedure that will take place during the Design and realization steps. Especially the newer version of the machine guidance will be deeply studied to understand the possible links between a BIM approach and the heavy machinery.

1.2 Structure of the thesis

This thesis is organized in a way to give the reader a series of paragraph that are fully focused on specific part of the problem, such paragraph are used to give a wide background to what will be discussed later. Within chapter 2 is presented the state of the art of the technology that is surrounding the problem studies. This means the presentation of the main hardware, software, approaches and schemas by describing in deep the practical aspects of each. Into the third chapter it is presented the state of the art about what is composing a standard BIM approach and a regular earthwork process. The aspects taken into considerations are the actors, the documents, the classifications and the steps that compose an excavation project.

Within chapter four, the theoretical approach, it will be explained the problems that have been studied, their origin and their applications. Furthermore, the software are studied to give the reader a better view of the parts that will be taken in exams during the explanation of the case study.

The purposes and the results contained into the thesis are then discussed into chapter five where it will be explained the experience of calibrating an excavator. It will be fully described the outputs of the machine guidance technology and the custom designed Dynamo script for surface merging will be shown in detail with its linked results. Then three main applications of the integration of the Machine guidance, BIM and GIS are expressed in terms of approach and steps that are may be suitable for achieving the desired results and benefits included into the automatization of the processes and the BIM approach

2 State of the art of the technology

The integration of BIM within the earthwork process is useful to generate a cooperation between the model of the building that will be erected or in case of site with existing structure is important to have a clear idea where those are located to prevent accident like passing with a 30-ton machinery over an existing underground structure that may collapse.

2.1 BIM-IFC

As already introduced the main requirements to achieve the benefits of this design approach is the interoperability. For a construction process many figures with different tasks and background are asked to contribute with reports, calculations and drawings. The issuing of a standardized language called IFC (industry information classes) came in help to ensure the interchange of data between different BIM oriented software of the various disciplines. IFC is an object-oriented open standard [12] and a neutral and open file format and is not controlled by a single company but is developed by the international not-for-profit organization, BuildingSMART [1]. The IFC schema was initiated in 1994 and has become a formally registered international standard as ISO/PAS 16739 [12]. IFC supports many types of geometric representation connected with a rich semantic information, such as owner information, modification history of the model, and cost and schedule of building components. That's why BIM model based on IFC are used for feasibility studies, tendering, code checking and operation management. The IFC standard is structure in a hierarchical and modular framework, which is divided into four bottom-up layers i.e., resource layer, core layer, interoperability layer and domain layer, and each layer consists of several modules which further contain entities, types, enumerations, rules and functions [14]. The entities are used as abstraction of objects or non-physical objects which have assigned by the standard most of the possible properties, via Property sets table. Being a hierarchical schema, all the properties of the entities above will be shared with the derived entities.

Passing from a traditional approach to a BIM based approach means facing different problems such as: change of process organization, requires time for the implementation, initial costs linked to software hardware and employee training.

2.1.1 The three pillars entities of an IFC model

An IFC model is integrated with hundreds of entities, like construction elements (IfcWall), geometric elements (IfcExtrudedAreaSolid) and basic construct (IfcCartesianPoint). The main logic is based on three fundamental concepts: IfcObjectDefinition, IfcRelationship and IfcPropertyDefinition. We can consider those

three entities as responsible to forming the first level of specialization within an IFC class hierarchy.

The first is IfcObjectDefinition defined by IFC4_ADD2_TC1 – 4.0.2.1 [15] as *"the generalization of any semantically treated thing or process, either being a type or an occurrence. Object definitions can be named, using the inherited Name attribute, which should be a user recognizable label for the object occurrence. Further explanations to the object can be given using the inherited Description attribute. A context is a specific kind of object definition as it provides the project or library context in which object types and object occurrences are defined."*. Objects are independent pieces of information that may contain or reference other information. Moreover, the schema provides four different kinds of relationship in which object definitions (by their instantiable subtypes) can be involved:

- **Assignment of other objects** - an assignment relationship (IfcRelAssigns) that refers to other types of objects and creates a bi-directional association. The semantic of the assignment is established at the level of the subtypes of the general IfcRelAssign relationship. There is no dependency implied a priori by the assignment.
- **Association to external resources** - an association relationship (IfcRelassociates) that refers to external sources of information (most notably a classification or document) and creates a unidirectional association. There is no dependency implied by the association.
- **Aggregation of other objects** - an aggregation relationship (IfcRelAggregates) that establishes an unordered, spatial whole/part relation and creates a bi-directional relation. There is an implied dependency established.
- **Nesting of other objects** - a nesting relationship (IfcRelNests) that establishes an ordered, non-spatial whole/part relation and creates a bi-directional relation. There is an implied dependency established.
- **Declaration within a context** - a relationship (IfcRelDeclares) of the uppermost object definition within the object definition tree (e.g., the summary object within an object nesting tree) to the context (a project or project library). It applies the units, representation context and other context information to this object definition and all dependent ones.

So, the IfcObjectDefinition class contains all the useful objects to full describe a construction asset, no matter if is abstract or tangible. Example of objects are walls, roofs, spaces, conceptual objects, grids, or process and people who perform those.

The schema then identifies 6 fundamental concepts that are directly connected to IfcObject class [15].

Entity inheritance
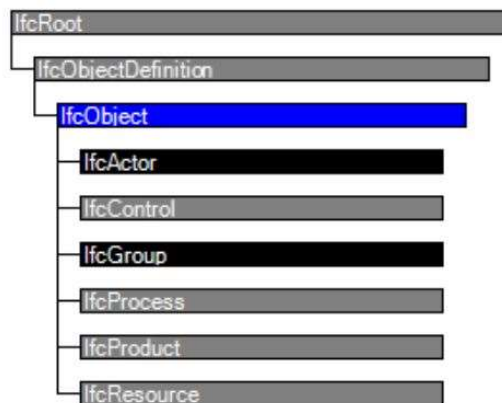
Figure 1 - IfcObject entity inheritance - [15]

1. The **IfcActor** defines all the actors involved in the construction process.
2. The **IfcControl** is the abstract generalization of all the concepts that control or limit the use of products, processes or resources in general. Therefore, it represents the design constraints [16]. In the earthwork field this is the aspect that govern the choice of machinery and guide the evaluation of the quality of the work performed because time constraint is crucial. For example, within this class we can include the elements that influence project planning, for instance:
   - client's requests
   - project costs
   - regulations and standards
   - delivery times

Entity inheritance

Figure 2 - ifcControl elements associated - [15]

3. **IfcGroup** "is a generalization of any arbitrary group. A group is a logical collection of objects, it does not have its own position, nor it can contain its own shape representation. Therefore, a group is a topological aggregation. For

example, we can associate a selection of elements of a structural frame in a group that are warped according to a specific direction." [16]
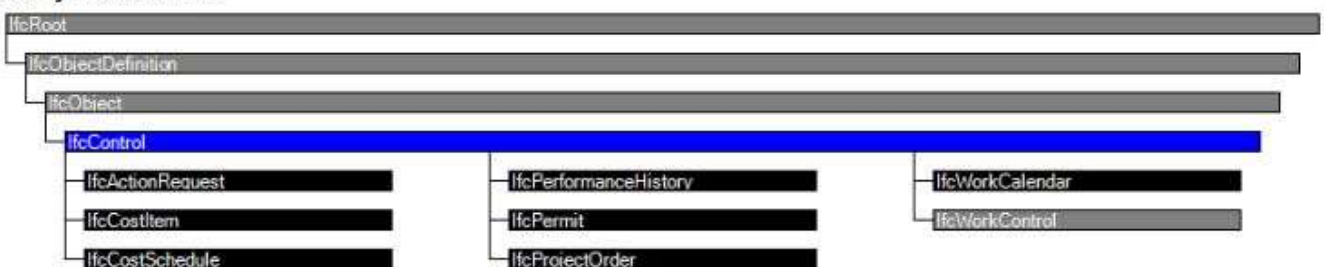
4. The **IfcProcess** represents activities, events and procedures that occur over time. This is the main definition of an excavation process because it is made from a series of actions that are repeated over time and only the results are tangible (volume excavated). The IfcProcess is defined as a single activity or event, which is:
   - ordered in time
   - has sequence relationships with other processes
   - transforms input into output.

5. **IfcResource** is an abstract generalization of the different resources used in construction projects, mainly labour, material, equipment and product resources, plus subcontracted resources and aggregations such as a crew resource [15]. It contains the information needed to represent costs, planning and other impacts from the use of an asset in a process. For example, for cost estimating purposes, construction equipment such as vehicles or earthworks machinery, which are not currently modelled within the IFC, these can be considered as an IfcResource [16]. Of course, according to the type of resource that is described it comes with different properties.

Entity inheritance

IfcRoot
IfcObjectDefinition
IfcObject
IfcResource
IfcConstructionResource
- IfcConstructionEquipmentResource
- IfcConstructionMaterialResource
- IfcConstructionProductResource
- IfcCrewResource
- IfcLaborResource
- IfcSubContractResource
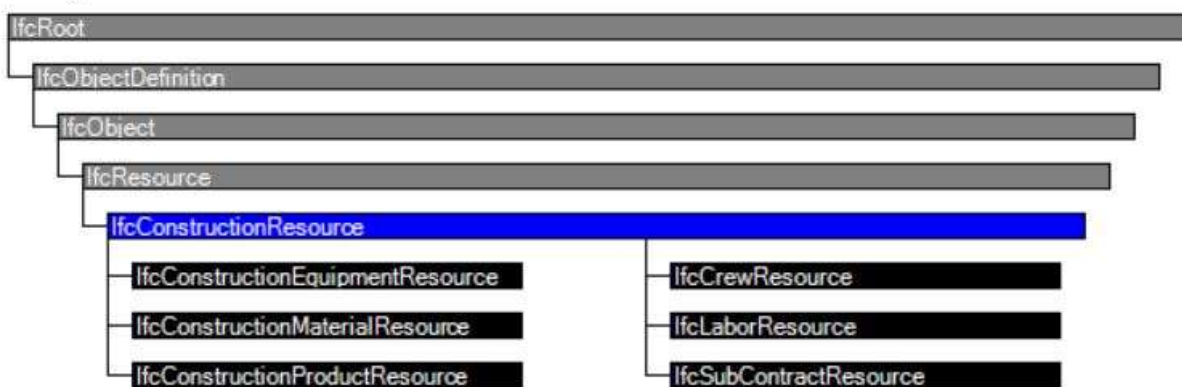
Figure 3 - IfcCostruction Resource inheritance - [15]

6. The IfcProduct includes any entity that can be related to a geometric / spatial context. Each entity has a specific location in space when it has a geometric representation assigned. This representation can be expressed in relation to other entities, but it will certainly be referenced with respect to the project coordinate system. In addition to real entities, the IfcProduct also includes non-physical elements, such as grids, notes, structural actions. For the purposes of an earthwork project the IfcProduct can be seen with an import value rather

than export, because while exporting an earthwork project in IFC we should neglect all the elements coming from the other disciplines.

What have been said about IfcObject can be summarized by the following picture.
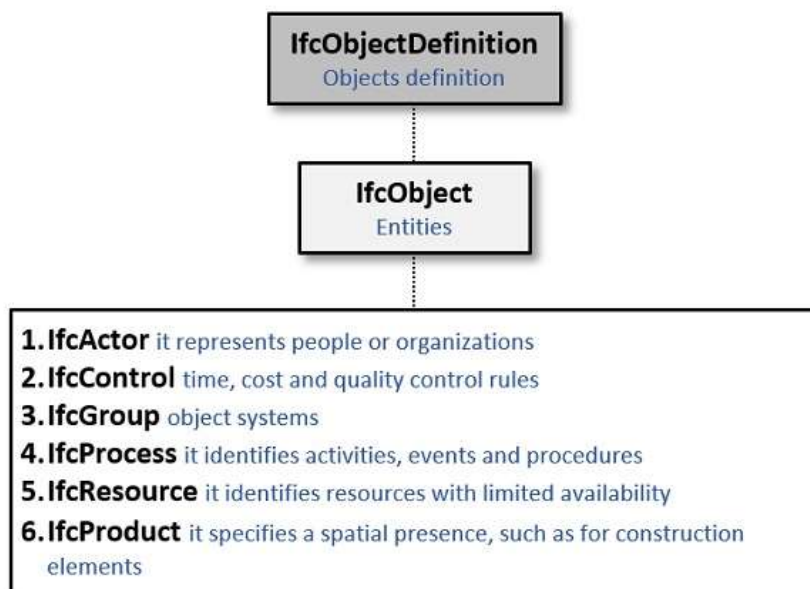
As a second pillar of the IFC schema we find IfcRelationship that is addressed to summarize the existing relationships between entities. It allows to keep relationship specific properties directly at the relationship and opens the possibility to later handle relationship specific behaviour [15]. It defines different types:
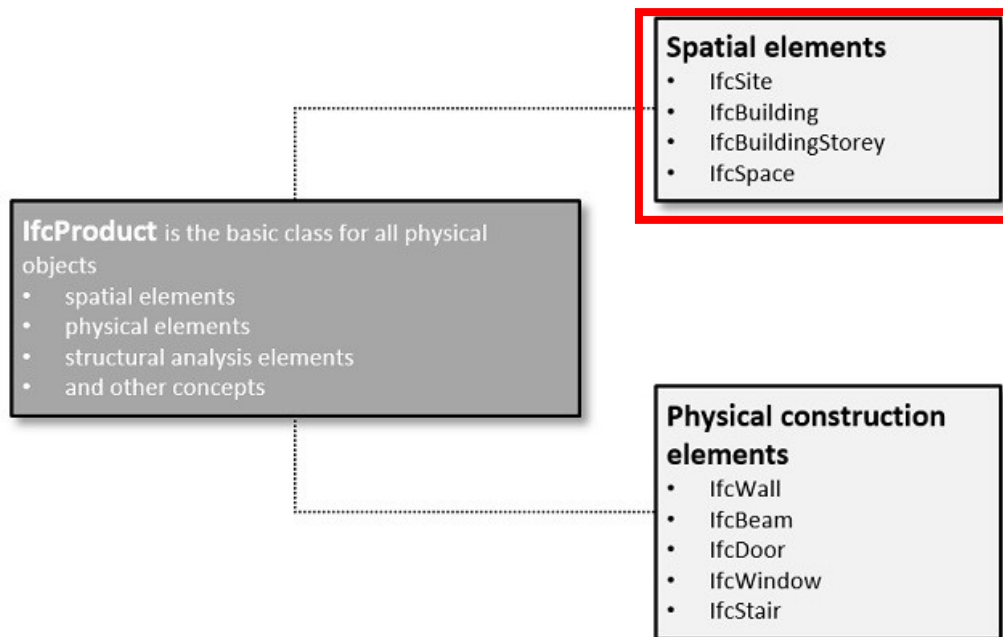
1. IfcRelConnects express the actual connection between two building elements.
2. IfcRelAssociates is an association of the element to a source of information (library, approval, document, etc) that may reside internally or externally of the project data. This relationship is one-way only.
3. IfcRelDecompose defines the general concept of elements being composed or decomposed. It denotes a whole to part hierarchy with the possibility to navigate from the whole (the composition) to the parts and vice versa.
4. IfcRelDefines is a relationship that allow an object instance to inherit a property set. It allows to define the object instance by: Object, Properties, template or type.
5. IfcAssigns it generalize the "link" relationships among instances of IfcObject. It establishes a bi-directional relationship among the participating objects and doesn't imply any dependency.
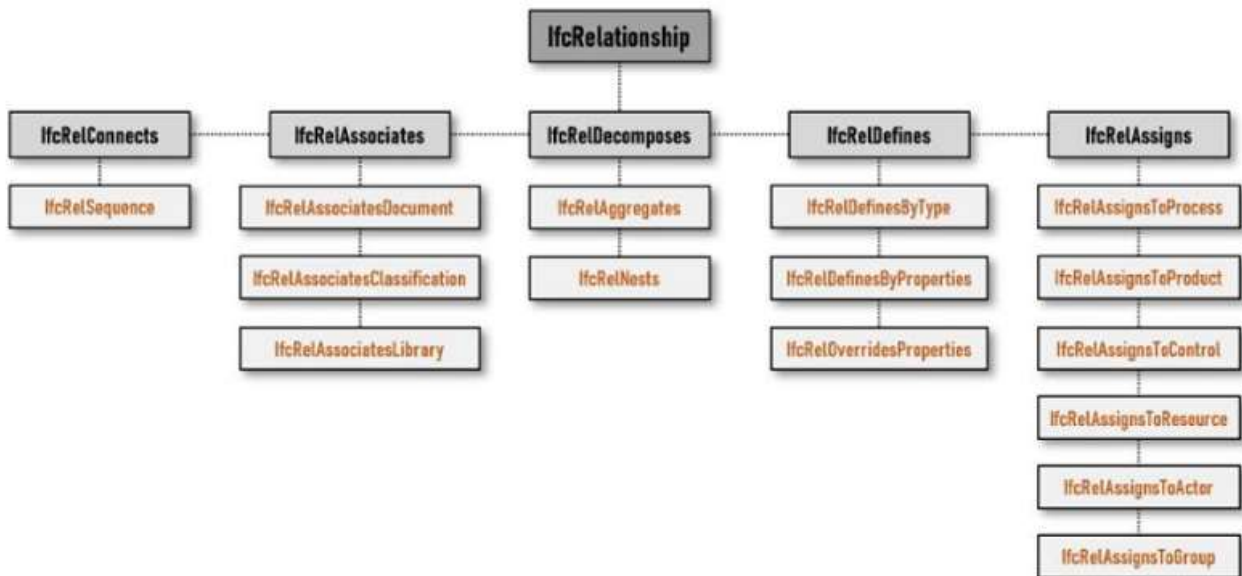
Figure 6 - IfcRelationship subdivision - [16]

The last pillar of the architecture of an IFC model is constituted by the entity IfcPropertyDefinition that express the idea of property as shared information among multiple object instances, and it allows to generalize all the possible assignable properties. This method allows to define one of the most important things inside an IFC file, which are the property sets and object types.

It is important to describe the path to arrive to a specific property, so we will follow the definition of a simple properties.

Starting from IfcPropertyDefinition we generalize all the characteristics that may be assigned to objects. Then we move to IfcPropertySetDefintion which generalize all the property sets. Going down by another level we may define the entity IfcPropertySet that is the actual container of all the properties related to a specific type or category of object. Is possible to visualize this concept as a premade (or custom if user defined) list of all the traits that the object can have, and then it will be exported if populated or if automatically filled by the software.

Entity inheritance

IfcRoot
IfcPropertyDefinition
IfcPropertySetDefinition
IfcPropertySet

Figure 7 - IfcPropertySet inheritance - [15]

Attribute of IfcPropertySet is IfcProperty that is subdivided in simple or complex which is used to define a property composed by different simple or complex properties.

Entity inheritance

IfcPropertyAbstraction
IfcProperty
IfcComplexProperty
IfcSimpleProperty

Figure 8 - Property Subdivision - [15]

Consequently, the property has different types, and the next subdivision allows to define which kind of values should be filled in a specific property. All these expected value types are able to cover all the cases. It is so possible to define values by ranges, single, enumeration (taken from a prefixed list), tables, reference and lists. It is possible to visualize what have been presented thanks to the picture below.
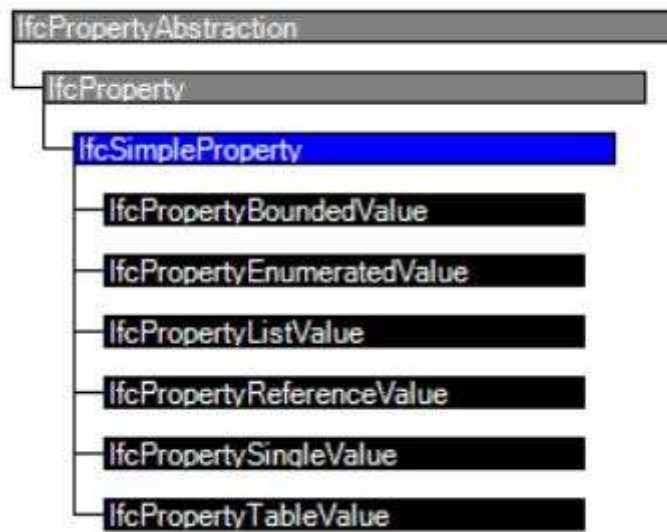
Entity inheritance

IfcPropertyAbstraction
IfcProperty
IfcSimpleProperty
IfcPropertyBoundedValue
IfcPropertyEnumeratedValue
IfcPropertyListValue
IfcPropertyReferenceValue
IfcPropertySingleValue
IfcPropertyTableValue

Figure 9 - IfcSimpleProperty types of value – [15]

2.1.2 BIM intended workflow

We can see the example given by BuildingSMART about the usage of IFC, "where the AEC professionals on a given building project use different BIM programs. For example, the architectural advisors might use ARCHICAD, the structural engineers do their work in Tekla and the installation engineer uses Revit MEP. Each disciplines consultant can export an IFC file from their specific model, which is then shared with the other consultants and the contractors". But importing a series of IFC file into a single project file can be not always the ideal solution since it can make the project heavy and difficult to read due to the high amount of information. So, a more efficient solution can be to combine all the discipline in a federated model on an independent BIM program that can be used for coordination and quality assurance, an example of software can be Autodesk Navisworks. BIM-based collaboration can work the best with clear agreements between the actors. This require an ICT (Information and Communication Technology) specification and/or ICT process manual to be prepared specifying what, when and how the information is to be exchanged.

Naming of the files composing the BIM model should be consistent and coherent for all the disciplines to ensure that the IFC files are easy to understand for both internal and external project participants.

Part of ICT specification sees the Information Delivery Manual (IDM) is a method of specifying which data is to be exchanged between actors but also how and when data is to be exchanged. This is an important aspect to ensure that between all the digital

deliveries there will be no missing information, consequently all the actors know what is to be delivered and received at any given time.

Model View Definition (MVD) is specified by BuildingSMART as data sets useful to ensure that only the relevant data comes within an extracted IFC file. CV 2.0 specification as example of format can be used to conduct an overall quality control, such as checking for collisions, classifications and coordination of quantities between the discipline models. This format ensures that, for example the plumbing model doesn't export the columns components within its IFC file.

IFC models is hierarchically constructed. Thus, each model should contain, according to the IFC-guide, the adequate parameter to describe the project, site, level and so on.

The intended workflow between disciplines sees that each actor is owner of his model so when an IFC file is exported and used by another designer the second one should not make any change of it. As an example, if the designer of the earthworks defined certain cuts to be performed and the plumbing engineer needs some different cut in another position to allow the placing of the new object, he should ask the change to be made by the earthworks engineer. This allows all the participant to keep track of the changes inside their own model and so to update calculations and decisions.
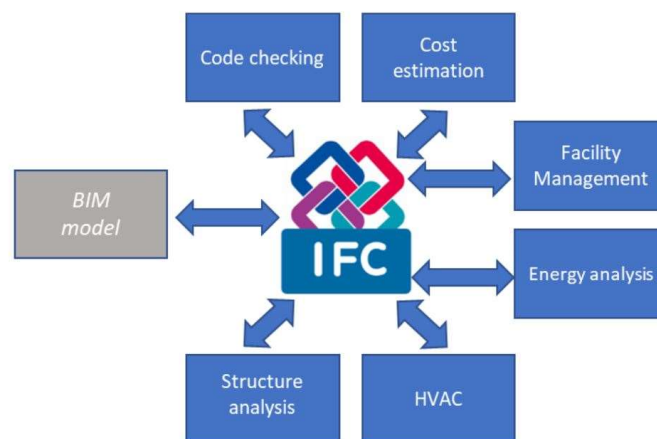
Figure 10 - An example of the interoperability benefits associated with the IFC schema (from: BuildingSMART international Website)

It is important to clarify that operating with some automatic calculation (or scripts) within a software is not BIM modelling but, BIM modelling can lead to some automatism.

2.3 GIS - CityGML

As we already said BIM aims to solve guarantee the interoperability between stakeholders in the AEC industry. But it has been reported that more than the 80% of

information could be referenced from geographical information [12]. So, from few years until now the BIM approach needs to be integrated with other systems in order to amplify and specialize the information. Geographical Information System, also abbreviated as GIS is a system to capture, store, manipulate, analyse, manage and present all types of geographical data [12], it is therefore an informative system that is able to associate the data to a geographic position. In the GIS model system, there are three types of information:

- Geometric: related to the representation of the objects on a map, such as point, line or polygon with their actual dimension.
- Topological: referred to the reciprocal information among objects
- Informative: regarding data associated to any object (as example below)

GIS is then managing the information in a relational database.

An example of concept of usage of GIS can be found in a map created by E.W. Gilbert in 1958 using the description and statistical data of John Snow about the cases of cholera and pump locations in the Soho district in 1854 where it can be seen points (geometric data) that carry an information such as "pump" or "death".

Figure 11 - Cholera cases Map - E.W. Gilbert (1958) [19]

So, we can safely say that what characterize the GIS is that it memorizes the position of data using a real projection system that defines the geographical position of the

object. It manages at the same time the data coming from different system (UTM or Gauss Boaga). The scale in GIS is defined as a quality parameter and visualization, the value of the scale expresses the significant digit that should be considered as valid [19].

The types of geographic data are basically two: vectorial and raster. The vectorial data are made by elements such as: point, lines or polygon. So, a point is identified with is real coordinates (x_1, y_1) and the more complex shapes by the position of their nodes or vertexes $(x_1, y_1; x_2, y_2; x_n, y_n)$ and to each element is attached a record of the database which contains all the values of the attributes associated to the represented object. The raster data represent the real world using a matrix of pixels and to each of those is associated the information of the element that are representing. These two types of data are used referring to different purposes. Usually, the vectorial type is used to represent object with discrete variability while the raster is used to represent wider parts of the map [19]. We can see that the mapped data coming, for example, from an excavator equipped with GNSS RTK system are of the GIS vectorial data. More specifically a 3D GIS, because it describes a specific point on the map with elevation and longitude/latitude. Furthermore, from the machine we can gather the information about productivity and activities performed and each line is then linked to specific position of the map with a precision of 8 digits after the zero.

Start Time (Europe/Rome)	Operator	Cycle Name	Total Cycle Time(s)	Cycle Fuel (L)	Moved Payload (t)	Start Lattitude	Start Longitude	Destination Lattitude	Destination Longitude
Report Generated Date: 16/06/2022 11:32:46 UTC									
10/06/2022 07:56:09	example	In attesa	18	0.0276	0	43.15462494	11.2787313	43.1546249	11.2787313
10/06/2022 07:56:27	example	Altro	98	0.7542	0	43.15462494	11.2787313	43.1546249	11.2787313
10/06/2022 07:58:06	example	In attesa	97	0.1077	0	43.15461349	11.2787743	43.1546135	11.2787743
10/06/2022 07:59:44	example	Altro	8	0.0842	0	43.15458298	11.2787533	43.154583	11.2787533
10/06/2022 07:59:52	example	Circolazione su strada	10	0.1307	0	43.15458298	11.2787533	43.154583	11.2787533
10/06/2022 08:00:02	example	Altro	7	0.1053	0	43.15458298	11.2787533	43.154583	11.2787533
10/06/2022 08:00:10	example	Circolazione su strada	2	0.0411	0	43.15458298	11.2787533	43.154583	11.2787533
10/06/2022 08:00:13	example	Altro	6	0.0816	0	43.15458298	11.2787533	43.154583	11.2787533
10/06/2022 08:00:19	example	Altro	1216	5.9214	0	43.15460587	11.2787104	43.1546059	11.2787104
10/06/2022 08:20:35	example	Circolazione su strada	1	0.0168	0	43.15460587	11.2787533	43.1546059	11.2787533
10/06/2022 08:20:37	example	Altro	38	0.4147	0	43.15460587	11.2787533	43.1546059	11.2787533
10/06/2022 08:21:16	example	Circolazione su strada	2	0.02	0	43.15460587	11.2787533	43.1546059	11.2787533
10/06/2022 08:21:18	example	Altro	3	0.0284	0	43.15460587	11.2787533	43.1546059	11.2787533
10/06/2022 08:21:22	example	Circolazione su strada	18	0.2461	0	43.15463638	11.2787104	43.1546364	11.2787104
10/06/2022 08:21:40	example	Altro	216	1.2462	0	43.15463638	11.2787104	43.1546364	11.2787104
10/06/2022 08:25:16	example	In attesa	432	0.3875	0	43.15471268	11.2786884	43.1547127	11.2786884
10/06/2022 08:32:29	example	Altro	6	0.0353	0	43.15464783	11.2786884	43.1546478	11.2786884
10/06/2022 08:32:35	example	Circolazione su strada	37	0.3593	0	43.15464783	11.2786884	43.1546478	11.2786884
10/06/2022 08:33:13	example	Altro	6	0.0509	0	43.1546669	11.2788172	43.1546669	11.2788172
10/06/2022 08:33:19	example	Circolazione su strada	16	0.2277	0	43.1546669	11.2788172	43.1546669	11.2788172
10/06/2022 08:33:35	example	Altro	7	0.0747	0	43.1546669	11.2788172	43.1546669	11.2788172
10/06/2022 08:33:42	example	Circolazione su strada	2	0.0338	0	43.15472031	11.2787743	43.1547203	11.2787743
10/06/2022 08:33:44	example	Altro	6	0.0681	0	43.15472031	11.2787743	43.1547203	11.2787743
10/06/2022 08:33:50	example	Circolazione su strada	3	0.055	0	43.15472031	11.2787743	43.1547203	11.2787743

Figure 12 - Example of Productivity file - CAT Advanced Productivity

One of the main schemas used in GIS field is CityGML (City markup language) developed by SIG3D. It was adopted as an official OGC (Open Geospatial Consortium) standard in 2008 [12], and unlike the original IFC syntax, EXPRESS, it is written in XML.

Anyway, nowadays the IFC can be also written in XML or Json. Its main feature is being able to represent the city objects using 5 level of details Lod 0 – 4.
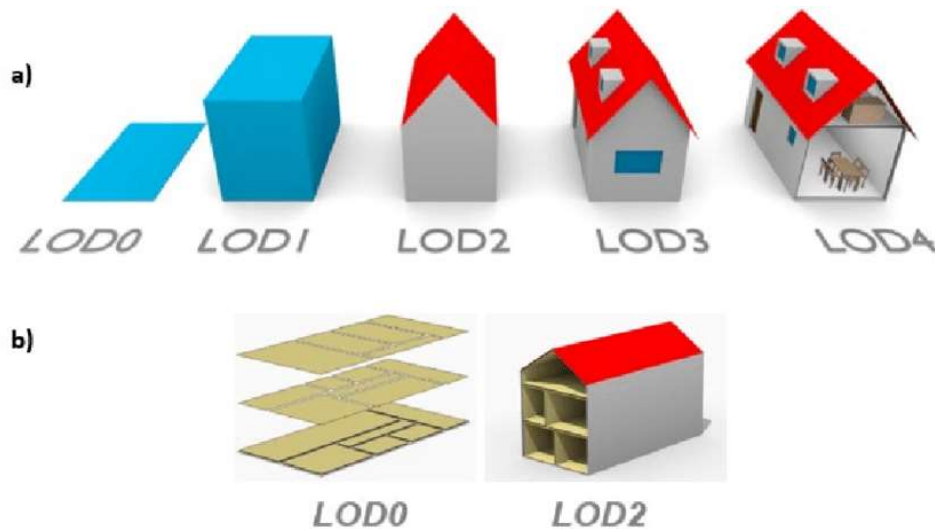
It starts from LoD0 which is a regional 2D map and it keep increasing elements until Lod4, where also the inside component of the building is included (e.g, Furniture). A LoD0 is simply a 2.5-dimensional digital terrain model which is a two-dimensional map with a 3D terrain. LoD1 models are simple box models. LoD2 adds the roof shape elements. LoD3 are included external feature of the buildings. LoD4 are then included the internal features [12]. Like IFC, is component based, so the information about a single building component can be extracted separately.

2.4 BIM - GIS integration

The integration between the two schemas will allow the interoperability between the disciplines that rely on geographical data with the others already implemented inside the BIM cycle. BIM and GIS integration can help to solve practical problems since are complementary to each other on smart city and digital twin [12]. BIM can cover the field of building information, cost and QTO management while GIS can focus on the analysis of the geospatial information. The GIS/BIM integration has been applied to many situations, Zhu J. and Wu P. [58] listed some of them: 3D cadastre visualisations, construction safety/ risk management, highway planning, green/ low-energy building design, indoor route planning and navigation and more.

Yichuan Deng et al. [12] developed a mapping framework between IFC and CityGML identifying the following challenges:

- Transformation of geometry among BRep, Swept Solid and Constructive Solid Geometry (CSG)

- Coordinate system transformation
- Schema mediation using reference ontology for different sets of terminology from IFC and CityGML
- Transformation among different LoDs in City GML

The first challenge comes from the difference of semantic representation of the object's geometry. Models can be classified as explicit if represented by explicit points, such as boundary representation(B-Rep) or implicit if they are created from parametric modelling methods (CSG, Swept Solid) and represented by a set of parameters [12].IFC is able to represent geometry in both ways, commonly it used CSG or swept solid that are more parametric friendly, while the B-Rep is not always used. On the contrary CityGML uses mainly explicit modelling, for both surfaces and solids, due to its insufficient semantic support to parametric modelling. Once the geometry is BRep translated it can be directly expressed using CityGML.
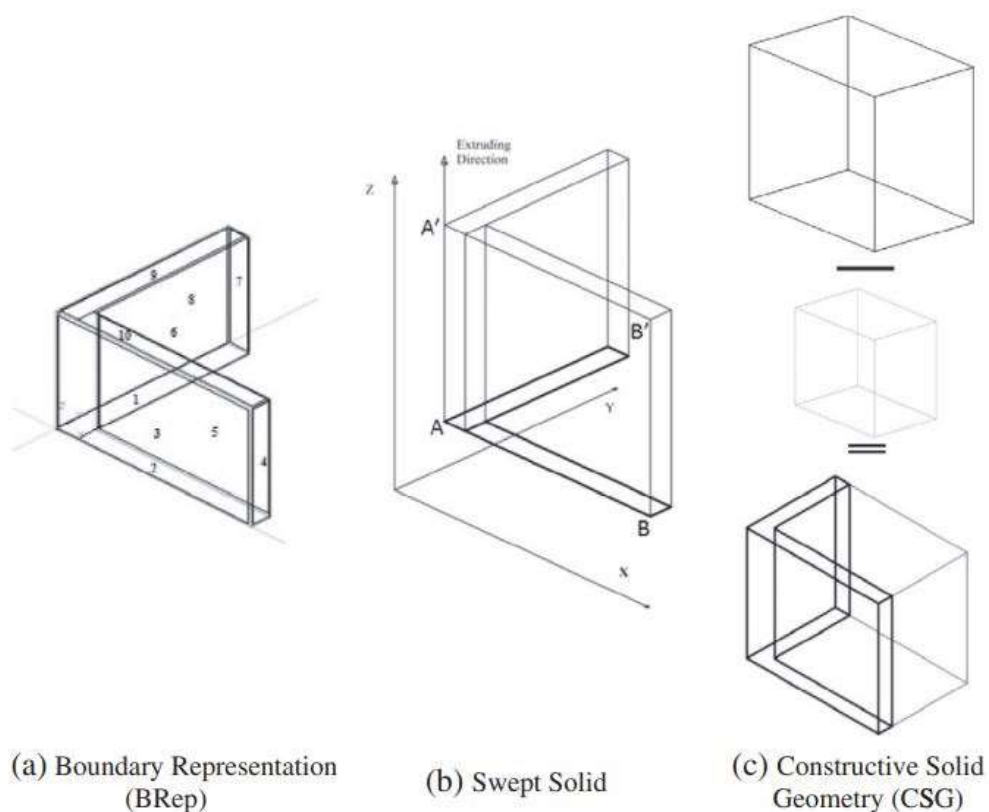

(a) Boundary Representation (BRep)   (b) Swept Solid   (c) Constructive Solid Geometry (CSG)

Figure 14 - BRep, Swept Solid and CSG, [12]

According to J. Zhu and P. Wu [58], in order to ensure a fluent information flow between BIM and GIS, the source of information, i.e., BIM models, should be accurate and reliable, with well-defined modelling accuracy and embedded geo-referencing information; information flow paths should be more robust and efficient. The dominant IFC-toCityGML path is still problematic, in terms of both geometry

conversion and semantics transfer. The use of surface models determines the complex solid-to-surface transformation, and the intrinsic semantics mismatch between IFC and CityGML leads to inevitable information loss; the destination of the information flow should be flexible.

The challenge of the coordinate system transformation is presented because the IFC instances are located in the space using a system of local coordinates (e.g., using IfcLocalPlacement) also called engineering coordinates system that is usually placed in a known geographical location. In the BIM approach IFC uses the LCS in a cascade way, creating a hierarchy of coordinate system [12]. On the contrary GIS method is based on a global coordinates system that is the real world, for example WGS84 (world Geodetic system 1984). To translate the coordinates of a point from a local to a global coordinate system Zhang S. et al. [33] provide the calculation to construct a 4 x 4 transformation matrix to be applied to the known point to get its new coordinates. The calculation is briefly reported below.

In a BIM model known a point X_0 with coordinates (x_0, y_0, z_0) that refers to a coordinate system placed in a point P with known longitude, latitude and altitude. A cartesian position represented by $X_1(x_1, y_1, z_1)$ can be returned from the values specified for P. Since both systems use right-handed systems, the transformation relationship between them can be described by a rotation matrix R and translation vector T [33]. The difference between a left- or right-handed system is the verse of the vector z (see picture below).
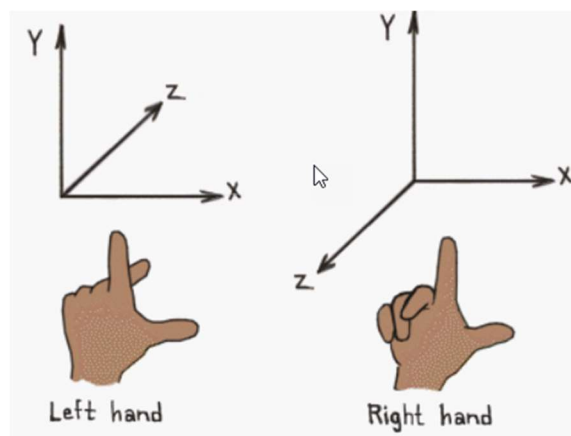

Figure 15 – Left- and right-handed coordinate system - [34]

To get the transformed point we should multiply the BIM cartesian point per the transformation matrix T_R that is defined as the product between R and T where the matrix R is calculated by the 3D components of the rotation.

$$X_1 = X_0 T_r$$

$$T_r = RT$$

$$R = R_z R_y R_x$$

$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos\theta_x & sin\theta_x & 0 \\ 0 & -sin\theta_x & cos\theta_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad R_y = \begin{bmatrix} cos\theta_y & 0 & -sin\theta_y & 0 \\ 0 & 1 & 0 & 0 \\ sin\theta_y & 0 & cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad R_z = \begin{bmatrix} cos\theta_z & sin\theta_z & 0 & 0 \\ -sin\theta_z & cos\theta_z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ T_x & T_y & T_z & 1 \end{bmatrix}$$

$$X_0 = [x_0 \quad y_0 \quad z_0 \quad 1]; \quad X_1 = [x_1 \quad y_1 \quad z_1 \quad 1]$$

Where θ_x, θ_y and θ_z are the angles of rotation about the X,Y and Z axis and T contains its translation components. This challenge is well explained and solved by C. Clemen et al. [5] thanks to their free and open software "IfcTerrain".

It is reported by the literature that the integration of the IFC and GIS is usually based on a reference ontology, see the references [12] and [33]. The complete definition is given by Deng. Y. et al *"In computer science and information science, an ontology is the representation of knowledge by using a set of pre-defined concepts within a domain and the relationship between concepts. In theory, an ontology is a formal, explicit specification of a shared conceptualization"* [12] this method is particularly useful while dealing with knowledge coming from multiple domains and it ensure the bidirectional exchange of data. A clear schema is then provided.
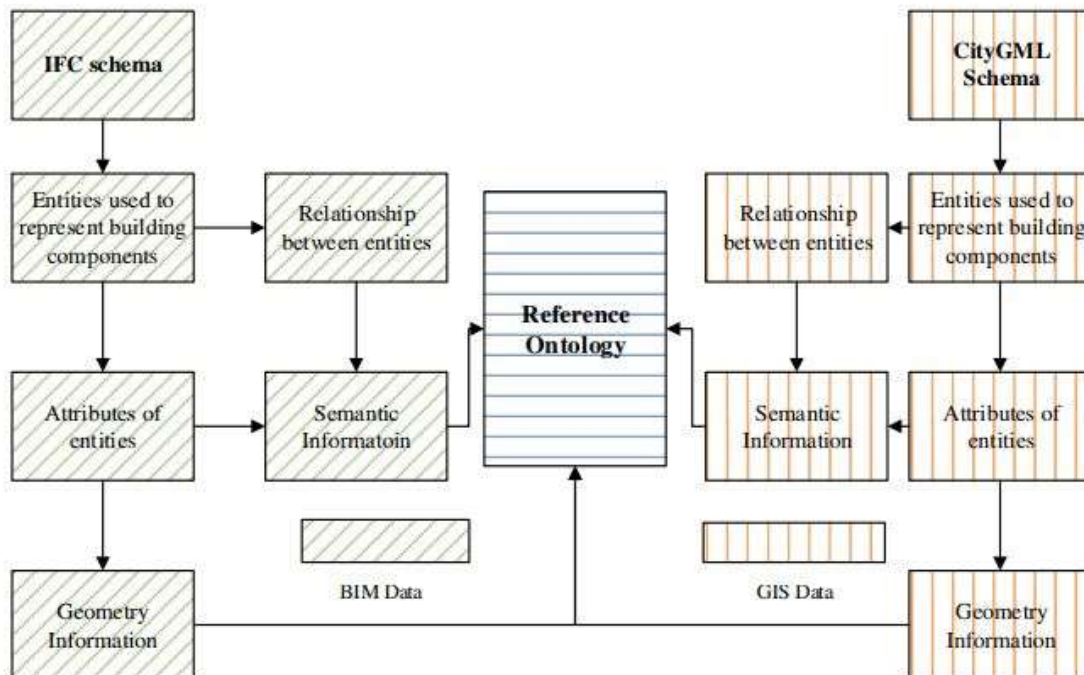

Figure 16 - Reference ontology Schema - [12]

Key point is to isolate what the two standards are describing, for IFC we should retrieve the property sets of instances and the various relationships while for GIS we should read the property linked to a specific coordinate.

A pertinent example of implementation of the BIM with GIS is the identification of buried structures such as pipelines or underground tunnels or rooms that may clash with the excavation operations. The BIM would benefit from the inclusion of geotechnical data which, in turn, would benefit the project management strategy in terms of cost and time. However, the main dependency is given by eh quality of ground investigation and construction monitoring and management [59].

Last but not least, the challenge of expressing which entity of IFC should be displayed according to the CityGML schema. A clear example is provided by Zhang S. et al. [33].
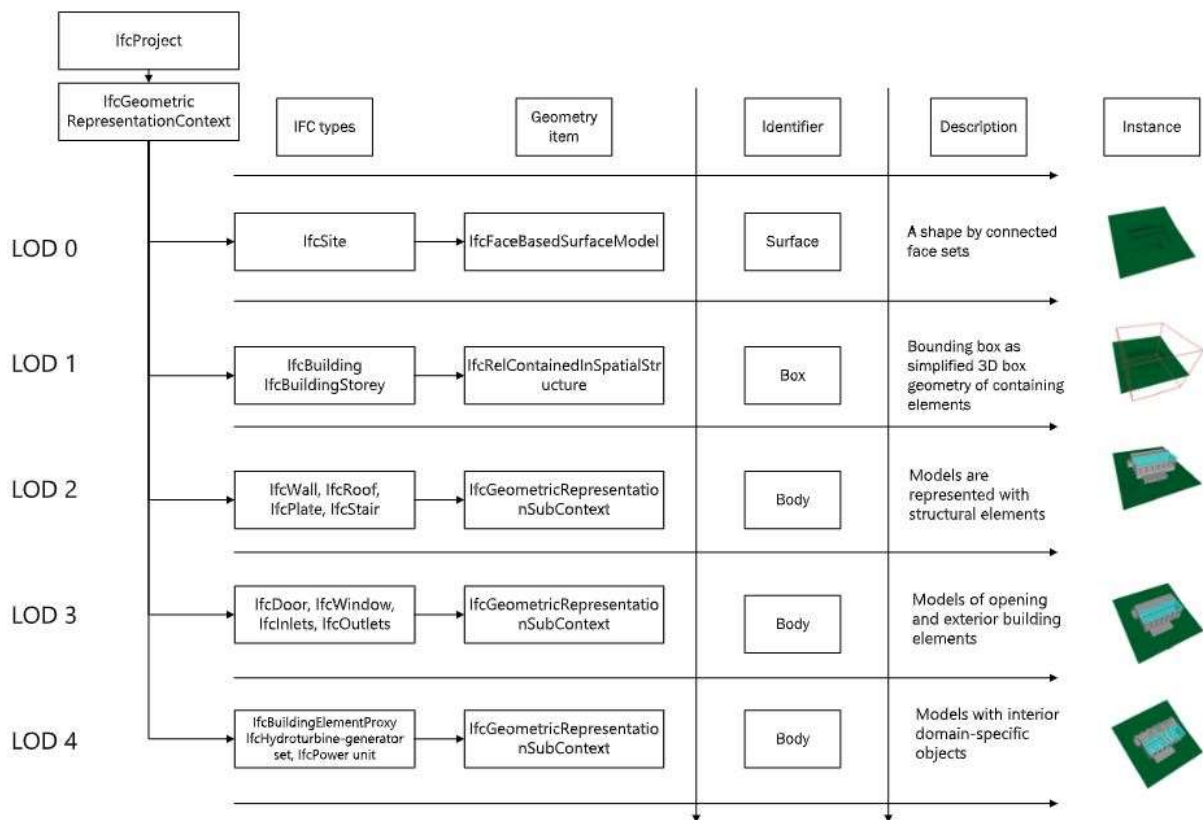

Figure 17 - LoD and IFC mapping - [33]

According to the LoD considered the IFC model is displayed with more or less entities. This step is crucial for keeping he consistency inside the model. LoD is a topic that concerns more for large georeferentiation of projects (e.g., Road design).

2.5 Translation of a topographical surface model using IFCterrain

IfcTerrain is specialized Extract-Transform-Load (ETL) tool for creating digital terrain models (DTM) using the Industry Foundation Classes (IFC) for OpenBIM projects. This

software can convert many standard formats and model representation of DTM. Main scope of this software is to keep unaltered the modelling procedures of the geospatial specialist within their software. BIM software and BIM common data environments (CDE) do not support all DTM model types and format that are currently used and exported by the geospatial specialists. Furthermore, BIM software currently are not always able to handle geo-referenced data and link them to actual geometric objects and task within the working environment. As already mentioned before the main goal of the BIM approach is to guarantee interoperability among the discipline and to define export schema to ensure the exchange of useful data.
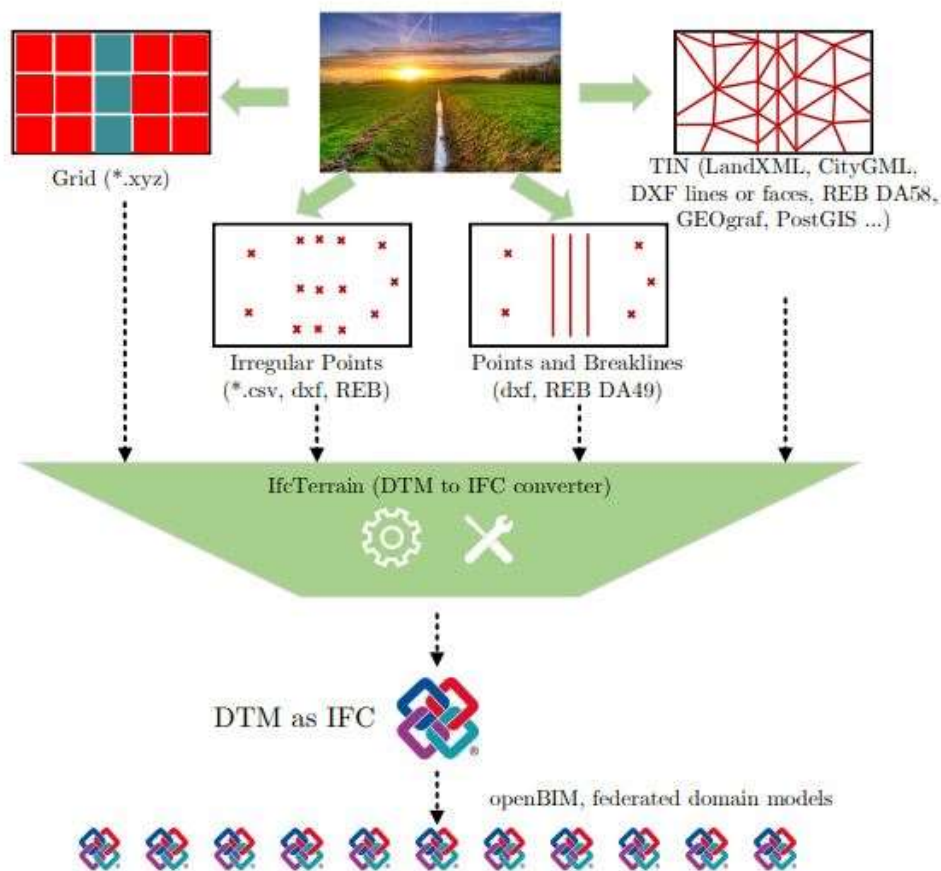
Figure 18 - From DTM to IFC - [5]

A DTM file independently form the format has as main contents:

- Points referred to the triangulated surface (TIN)
- Lines to delimit the modelled area
- Breaklines, lines to distinguish between terrain sections with different slopes

Taken as an example a LandXml format, it can be easily viewed with the note pad of any PC and using the extended Markup Language (XML) can be easily recognised each point by its ID and its XYZ coordinates, boundary lines (contour), configuration points

used for site calibration and all the faces of the triangulated surface. DTM also contains other properties that are useful for the specialist, such as treatment of water surfaces, fitting of engineering structures (bridge, tunnels) and natural overhangs. IfcTerrain so can help to deliver the DTM as IFC model to allow collision analysis, quality checks, architectural landscape planning, task of land management and as built control.

Currently IFC description for DTM used by IfcTerrain are the following:

1 IFC 2x Edition 3 Technical Corrigendum 1 (IFC 2x3 TC1) (ISO/PAS 16739:2005, 2005)
2 IFC Version 4.0 - Addendum Technical Corrigendum 1 (IFC 4 ADD2 TC1) (ISO 16739-1:2018, 2018)

As described by BuildingSMART in their webpage regarding Release notes the IFC scheme "IFC 4.3" has been candidate for validation, so is not yet official. This new release will contain support for infrastructure domains, earthworks, Geotechnical and so on, allowing to enlarge the scale of the IFC definition following their project of IFCInfra. Being candidate and so not yet official create a limit where the developers of BIM oriented software (and consequently IFCTerrain) still not include these fields within their export options. This extension of the standard is an initiative of BuildingSmart and aims to add material to the OpenBIM exchange process. OpenBIM is gaining importance since its aim is to bring transparent and sustainable data that will guarantee interoperability among actors and software, unlike its contrary, the ClosedBIM, which is characterized by the usage of proprietary software considered as "black boxes" in terms of processes and data structure [29].

2.5.1 Terrain as BIM object

BIM is an object-oriented scheme and IfcSite is already used for common practice, since is an abstract entity used to define area of land that will host the building or part of it. The position can be defined using global positioning WGS84 with Longitude, Latitude and elevation with a precision of a millionth of a second. So, we have defined in this way the point 0, 0, 0 of the LocalPlacement of a spatial structure element included IfcSite. Providing an IfcSite object with geometry is illogical since, by definition, is not but is a IfcSpatialStructureElement so it should be used for the topological breakdown structure of the project. The second variant proposed by the Tool is to use IfcGeographicElement that was introduced with IFC 4 and it allows to conceptualize the object representation and the spatial structure of the terrain separately. As can be seen in the picture below the variant that refers to the IFC 2x3 the relationship between IfcSite and IfcProductDefintionShape and

IfcShapeRepresentation is direct, while for the IFC 4 there is an additional entity, IfcGeographicElement that is a generalization of all elements within a geographical landscape.
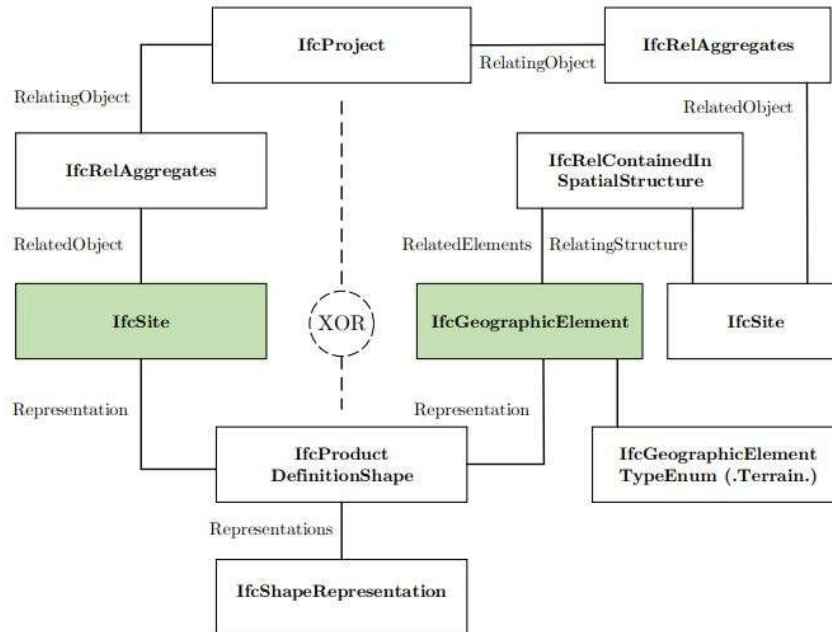

Figure 19 In IFCTerrain the Terrain is either be objectified as IfcSite (IFC 2X3) or IfcGeographicElement (IFC 4) – Ref [5]

2.5.2 Geometric Representation

While using IfcTerrain is possible to choose between three different types of geometric representation, the entities that will be described are then sub linked to the IfcShapeRepresentation that can be defined with the most suitable type GeomtricCurveSet or Tesselation. A DTM 3D surface is generally represented by triangulation, so the geometric components that we should consider are points and curves that connect them. Speaking in topological terms we are very interested in the position of the points since are vector of geographical information. Having a denser cloud of point means having more triangles and consequently a better approximation of the actual surface to the detriment of the time of processing the data at the model creation stage.
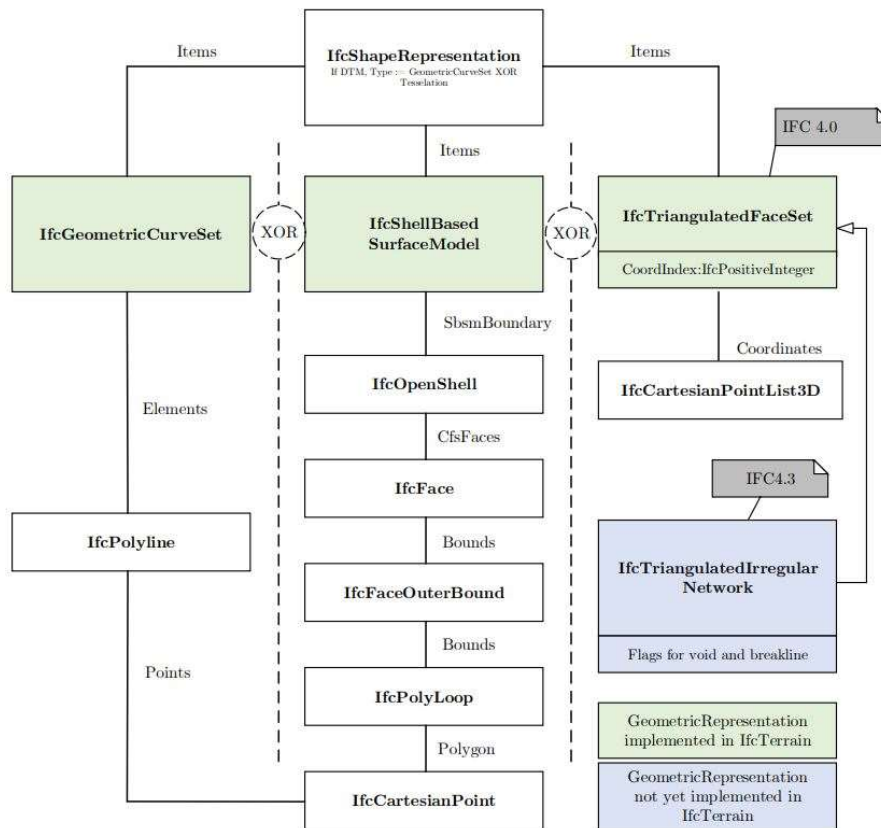
Figure 20 Geometric representation exported by IfcTerrain - Ref [5]

Since the IFC 2x3 scheme is possible to use IfcGeometricCurveSet which duty is to share 2D and 3D information of points and curves, thanks to a series of entities called IfcPolyline. This path may seem faster and less structured but in this way the surface will lose its topological structure, but it will become purely geometric. Looking at the IFC exported is clearly visible the result of this subdivision

```
#4914=IFCCARTESIANPOINT((-61.658633258368354,129.49703872203827,157.9179993));
#4915=IFCCARTESIANPOINT((-61.998633258393966,129.49703872203827,157.7799988));
#4916=IFCCARTESIANPOINT((-47.038633258373011,117.25703872181475,156.3370056));
#4917=IFCCARTESIANPOINT((82.841366741631646,-45.262961278669536,157.901001));
                #7496=IFCPOLYLINE((#636,#29));
                #7497=IFCPOLYLINE((#29,#7212));
                #7498=IFCPOLYLINE((#7212,#636));
                #7499=IFCPOLYLINE((#6113,#5211));
```

Figure 21 - Example of result from the IFC file exported using IfcGeomtricCurveSet

The Polylines are entity defined by two points that have been recalculated to the new system of axis and consequently been called with new unique IDs.

Another way of exporting the site information using IfcTerrain tool is using the entity IfcShellBasedSurfaceModel which definition according to ISO/CD 10303-42: 1992 is *"A shell-based surface model is described by a set of open or closed shells of dimensionality 2. The shells shall not intersect except at edges and vertices. In particular, distinct faces may not intersect. A complete face of one shell may be shared with another shell. Coincident portions of shells shall both reference the same faces, edges and vertices defining the coincident region. There shall be at least one shell. A shell may exist independently of a surface model."*, since the DTM is generally a surface that doesn't form a closed body is possible to represent it as a series of IfcFace with bounds and cartesian points. Using this method, the topological structure is retained in the IFC. But it will store each point as a single entity increasing the complexity of the file as shown in the picture below.

```
#22=IFCGEOMETRICREPRESENTATIONCONTEXT('Building Plan View','Plan',2,1.E-05,#21,$);
#23=IFCSITE('13EyCxz819KAHaAI1vhVGE',#2,'Terrain',$,$,#24,#46894,$,.ELEMENT.,$,$,$,$,$);
#24=IFCLOCALPLACEMENT($,#25);
#25=IFCAXIS2PLACEMENT3D(#26,#27,#28);
#26=IFCCARTESIANPOINT((508912.28863325837,5045616.5329612782,0.));
#27=IFCDIRECTION((0.,0.,1.));
#28=IFCDIRECTION((1.,0.,0.));
#29=IFCCARTESIANPOINT((-70.158633258368354,137.65703872218728,159.697998));
#30=IFCCARTESIANPOINT((-56.898633258359041,96.857038721442223,158.1009979));
#31=IFCCARTESIANPOINT((-56.898633258359041,110.45703872200102,156.3430023));
#32=IFCCARTESIANPOINT((-56.898633258359041,124.05703872162849,156.4420013));
#33=IFCCARTESIANPOINT((-56.898633258359041,137.65703872218728,156.3480072));
#34=IFCCARTESIANPOINT((-43.638633258349728,110.45703872200102,156.1959991));
#35=IFCCARTESIANPOINT((-43.638633258349728,124.05703872162849,157.7709961));
#36=IFCCARTESIANPOINT((-43.638633258349728,137.65703872218728,159.7660065));
#37=IFCCARTESIANPOINT((-30.378633258398622,-107.14296127855778,157.6459961));
#38=IFCCARTESIANPOINT((-30.378633258398622,96.857038721442223,157.5180054));
#39=IFCCARTESIANPOINT((-30.378633258398622,110.45703872200102,160.4909973));
#40=IFCCARTESIANPOINT((88.961366741626989,-202.34296127781272,155.776001));
```

Figure 22 - Sample of IfcTerrain export with IfcShellBasedSurfaceModel

Speaking about the third way of exporting we enter to the latest IFC 4 that includes IfcTriangulatedFaceSet that allows to store the points in a list called IfcCartesianPointList3D that will be referred inside the triangles by means of indexes. Additionally, the normal of each triangle is saved within the IFC guaranteeing a correct orientation of each "piece" of the model. With IFC 4.3 the concept of IfcIreggularTriangulatedNetwrok is introduced to the standard which will give the ability to distinguish between visibility and breakline vs. no breakline for each side of a triangle [5].

2.5.3 Georeferencing of the DTM

After the translation of the geometry into the IFC vocabulary IfcTerrain offers different solution for georeferencing the topography surface. The solution is based on the theory explained in "Level of Georeferencing (LoGeoRef) using IFC for BIM" written by Clemen Christian and Görne Hendrik published in the 2019. The reason why this article was written is "...because Building Models in IFC are often not perfectly or sometimes not at all georeferenced" [10]. At this stage we want to merge the BIM geometric information of the building with the topography information given by the GIS. The georeferencing is done through a coordinate transformation from the DTM coordinate system to another one. The ISO 19111 standard defines "the conceptual schema for the description of referencing by coordinates it describes the minimum data required to define coordinate reference systems" [12] and it should be used when at least one the system is related to a geodetic datum.

Georeferencing is important both for BIM and Geospatial, for example is needed for machine guidance, monitoring of work progress and site area management. According to the study of Clemen and Görne there are 5 proposed types of georeferencing.

2.5.3.1 LoGeoRef 10
This uses a postal address, that become useful and readable for humans and semi-structured for machines, such method can be considered the simplest way to describe the site location. IFC propose the entity IfcPostalAddress and must be reference by either IfcSite or IfcBuilding. This level of detail contained in the postal address is rough compared to other systems, but it can be useful for integrating GIS since it can be used to integrate the model of the surroundings. In the IFC file the postal address will be a standalone entity that will be then referenced inside the entities IfcSite and IfcBuilding.
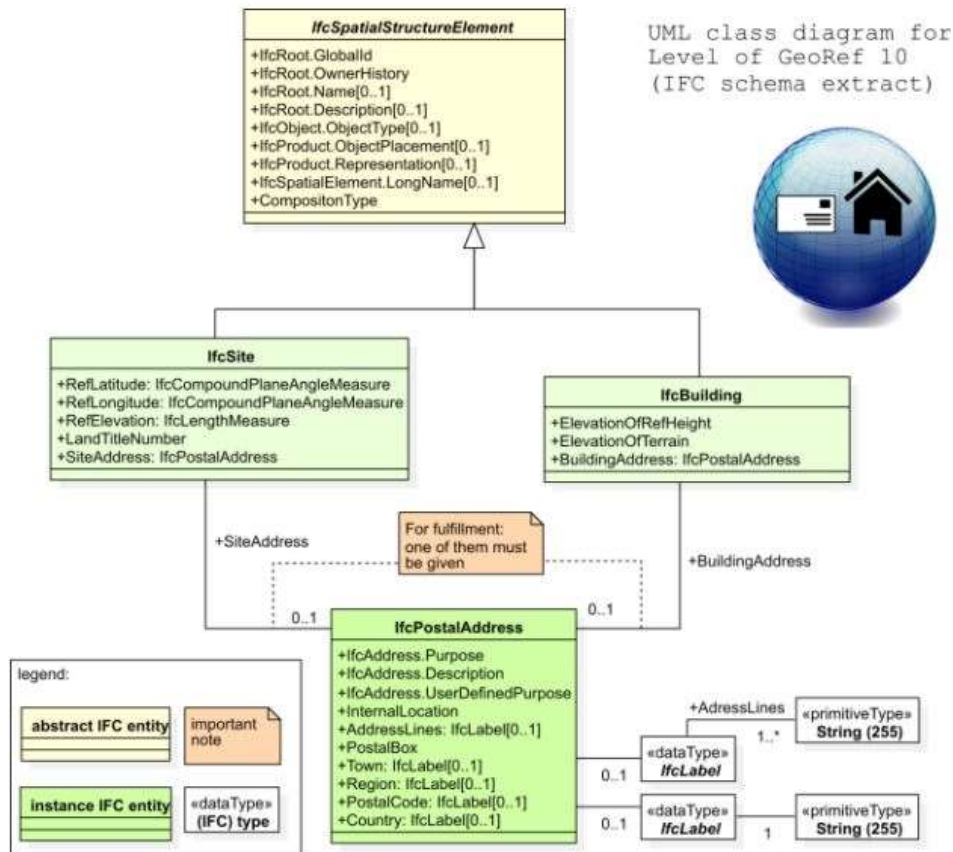
Figure 23 - LoGeoRef 10 - [10]

2.5.3.2 LoGeoRef 20

Georeferencing using geographic coordinates of a point on a map is one of the most intuitive and primitive way of locating a site in the globe. The entity IfcSite is already provided with the attributes RefLatitude and RefLongitude that should be filled to store a single reference point inside the entity itself. According to Building Smart the values should be defined using World Geodetic System. Furthermore, in the table reported below coming from the IFC schema, is possible to notice that also the RefElevation is an attribute of IfcSite and should be given as vertical distance from the sea level. The type of the attributes RefLatitude/Longitude is IfcCompoundPlaneAngleMeasure and according to the IFC schema web site is defined as a "compound measure of plane and angle in degrees, minutes, seconds and optionally millionth- seconds of arc" from the definition is clearly understandable that using IfcSite the reference point can be set in a very accurate way. But at this level is not possible to store any rotation parameters

Attribute definitions

| #	Attribute	Type	Cardinality	Description	G
10	RefLatitude	IfcCompoundPlaneAngleMeasure	?	World Latitude at reference point (most likely defined in legal description). Defined as integer values for degrees, minutes, seconds, and, optionally, millionths of seconds with respect to the world geodetic system WGS84. NOTE Latitudes are measured relative to the geodetic equator, north of the equator by positive values - from 0 till +90, south of the equator by negative values - from 0 till -90.	X
11	RefLongitude	IfcCompoundPlaneAngleMeasure	?	World Longitude at reference point (most likely defined in legal description). Defined as integer values for degrees, minutes, seconds, and, optionally, millionths of seconds with respect to the world geodetic system WGS84. NOTE Longitudes are measured relative to the geodetic zero meridian, nominally the same as the Greenwich prime meridian: longitudes west of the zero meridian have negative values - from 0 till -180, longitudes east of the zero meridian have positive values - from 0 till -180. EXAMPLE Chicago Harbor Light has according to WGS84 a longitude -87.35.40 (or 87.35.40W) and a latitude 41.53.30 (or 41.53.30N).	X
12	RefElevation	IfcLengthMeasure	?	Datum elevation relative to sea level.	X
13	LandTitleNumber	IfcLabel	?	The land title number (designation of the site within a regional system).	X
14	SiteAddress	IfcPostalAddress	?	Address given to the site for postal purposes.	X

Figure 24 - IfcSite Attributes definition - IFC 4 schema

2.5.3.3 LoGeoRef 30

Describe the possibility to attach the location of any IfcSpatialStructureElement to its local placement object. This method applies only to the spatial structure elements that do not have a relative placement to another spatial structure element. The attribute Relative placement is of the type IfcAxis2Placement3D, so X, Y and Z coordinates are stored with the vector components for an angle specification for a rotation of the X-axis and the Z-axis. In this way is possible to store the placement for the translation to an arbitrary coordinate reference system (CRS) in the attribute Location and the rotation (True North) as a vector of the specific axis of the attribute RefDirection. This level of georeferencing is still expected by many software but is conceptually wrong: Because IfcSite does not represent an object, but a spatial structure and the terrain should not be placed in the "inertial system", having no reference to nothing. [5]
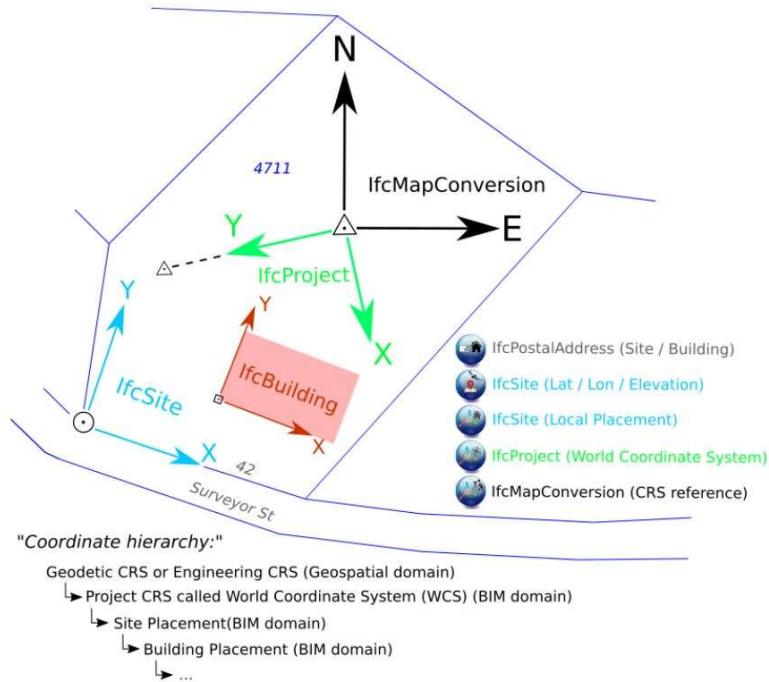
2.5.3.4 LoGeoRef 40

LoGeoRef 40 provides two attributes to store the georeferencing information in the IFC-file. They can be defined starting from IfcProject where we can see IfcGeometricRepresentationContext that has WorldCoordinateSystem and TrueNorth as attributes. This level of reference is so creating a well-defined coordinate system in the IfcProject, by providing the TrueNorth attribute included in IfcDirection it is possible to rotate the project against "true North" so level 30 and 40 can't be implemented at the same time. [5] As said at the beginning the higher the level of georeferencing the higher Is the level of detail given by the stored information, so a scheme is provided in the picture below.

UML class diagram for
Level of GeoRef 40
(IFC schema extract)
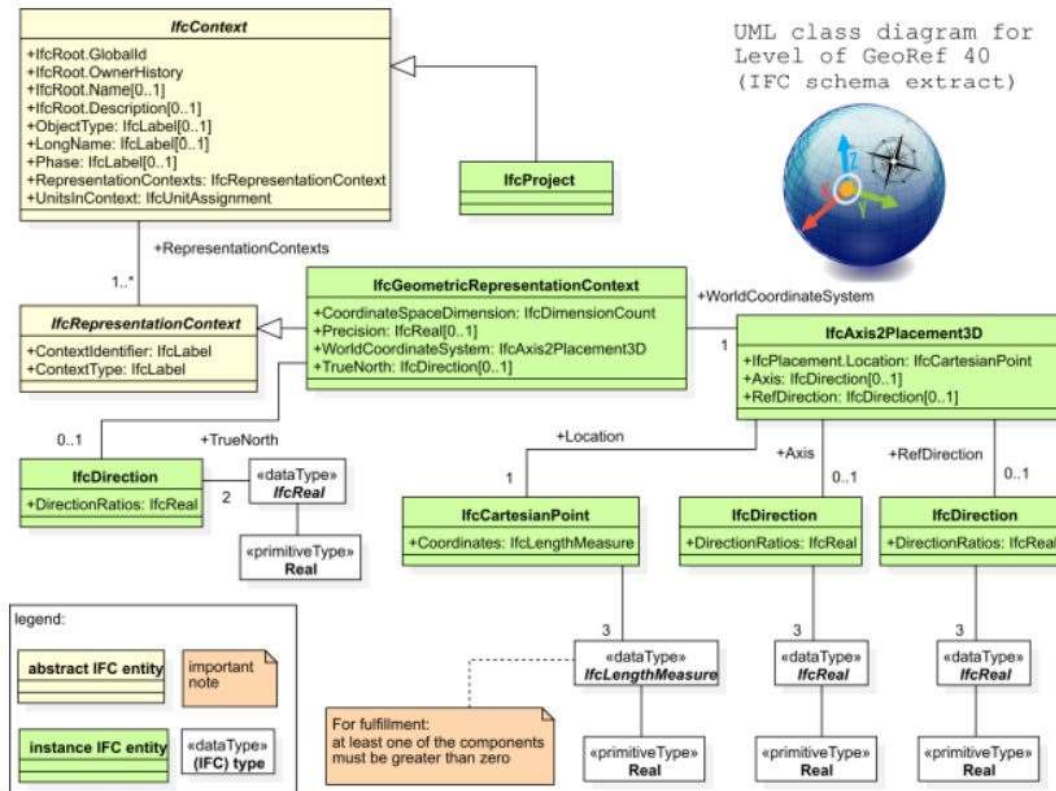
2.5.3.5 LoGeoRef 50

Is the more detailed Georeferencing method that an IFC-file can provide. It is only available if we consider the IFC schema version 4 so not all the software uses this standard. By introducing in the standard, the IfcMapConversion, that stores the offset between project coordinate system and the global origin of a coordinate reference system with the attributes Eastings, Northings and OrtogonalHeight, is possible to link it between IfcGeometricRepresentation and IfcProjectedCRS. So, both BIM and GIS software can calculate the georeferencing.

To conclude the listing of all the level is provided an overall scheme taken from "Level of Georeferencing (LoGeoRef) using IFC for BIM." [10]. Where is presented as a cascade the LoGeoRef from the first with IfcPostalAddress to the last with IfcMapConversion.

"Coordinate hierarchy:"
Geodetic CRS or Engineering CRS (Geospatial domain)
↳ Project CRS called World Coordinate System (WCS) (BIM domain)
  ↳ Site Placement(BIM domain)
    ↳ Building Placement (BIM domain)
      ↳ ...

And from the Reference [5] is extracted the IFC schema that can be followed as described in the previous subchapters.
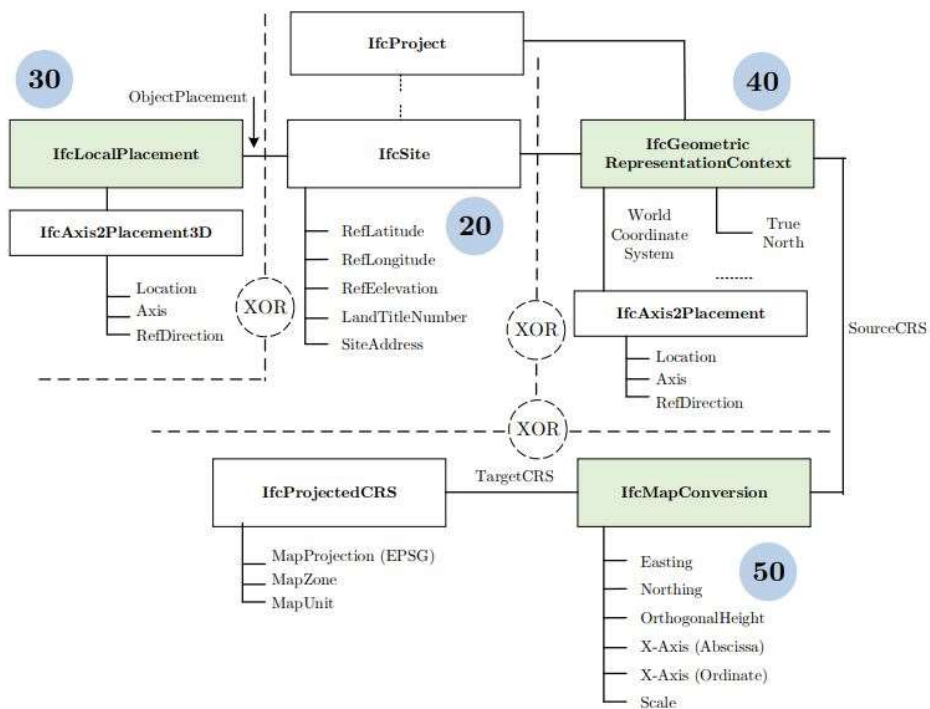
2.6 Survey tools comparison

Gathering the "as built" conditions is important if we want to keep track of the initial conditions or the progress of the excavation process. Many tools can be used to Create the DTM model and each of them has specific advantages and disadvantages.

These tools are used by the surveyor or the Geospatial engineer, that will design the excavation project. It is important to identify the most convenient method in terms of cost, "easy to use" and time of postprocessing. In order to provide a complete and correct comparison of the existing tools it is given a brief description of the type of data acquisition and limitations linked to each piece of equipment.

2.6.1 UAV

Unmanned Aerial Vehicles, usually referred to as drones, have become more common among the research study and site as-built surveillance. This new equipment is usually provided with an aerodynamical system composed by four rotor that can guarantee stability and good handling or can be VTOL (Vertical Take-Off and Landing) with fixed wing. For the image acquisition it is provided a camera placed in the front while for the georeferentiation there is a positioning receiver that can acquire the precise location through GNSS linked to the internet virtual reference stations (VRS).

Figure 25 - Dji Matrice 300 RTK four rotor (left) and a fixed wings UX5 (right)

Such drones are nowadays equipped with a self-driving technology, and the main advantage of the fixed wings is the resilience to more severe weather conditions. It can resist to wind speed up to 65 km/h, while for the smallest drone the resistance is up to a wind that blows at 36 km/h. These tools collect images as a coloured cloud of points where each element is georeferenced, and this procedure is performed during the scan activity that should be planned and performed with accuracy. The initial cost of these drones, around 10'000 € and more, can be prohibitive for certain companies. Especially if we consider that the drones can't fly in zone with restricted air traffic or if not provided of the correct permit. Anyway, lately among professionals a new model of drone is getting more attention, the Dji Phantom 4 RTK, thanks to his lower price (between 5'000 and 6'000 €) can be affordable but its weight (1391 g) and purpose still don't delete the need of the specific driving licence, since that according to the Italian law trough the ENAC (Ente Nazionale per l'Aviazione Civile) "for drones with weight over 250 g and for professional usage the drone driving licence is required, as well as an insurance". Anyway, the European

regulation 2019/945 and 2019/947 set out the framework for the safe operation of civil drones. The law is based on a risk-based approach, the EASA (European Union Aviation Safety Agency) divides the UAVs into three categories:

- Open: lower-risk civil drone operations, subdivided into A1, A2 and A3 and doesn't require operational authorisation before a flight.
- Specific: is the category that covers the riskier civil drone operations, it requires the operator to obtain an operational authorisation before flight after performing a risk assessment linked to the procedure.
- Certified: the risk is considered considerably high.

All these limitations and documents required doesn't suit the dynamic sequence of the events within a construction site.

Following what in the literature is usually explained the procedure for UAV survey start with the setting of a certain number of GCP (Ground Control Point), that will be used for aerial triangulation. Then is possible to define some checkpoints, called CHP, useful for accuracy verification for the created DEM (digital elevation model). Longitude, latitude coordinates and orthometric height of the GCPs can be recorded using network RTK survey or any other positioning device, the targets are prepared as shown in the picture taken from a study carried by Kavaliauskas P. et al [46],
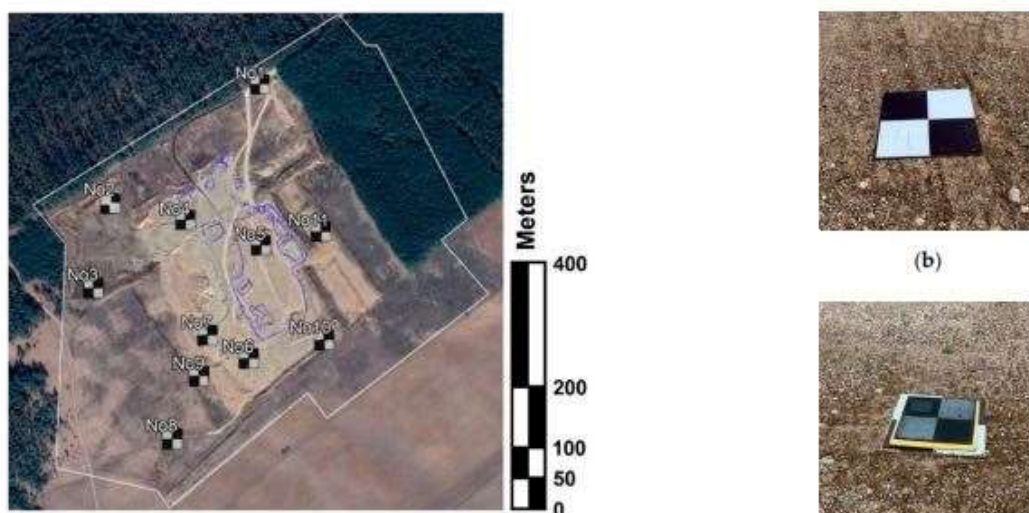

Figure 26 - Targets placed within the GCP and CHP location - [46]

After this preparation it is designed the path, usually with a photogrammetry 2D nadir pattern, that the drone will follow during the mission. During the drone will take a certain predefined amount of scan (pictures) according to the desired density of information. After the flight the surveyor will process the cloud of points with a GIS oriented tool, extracting the DTM needed. The volume is then usually calculate using

the Volume Dashboard Tool of Autodesk Civil 3D, which compare the previous and the existing TIN surfaces.

Drones are potentially a good candidate for site surveillance of the as built conditions, it is reported that with an RTK system the precision can be millimetric and the loss of data is reported to happen mainly if the drone antennas lose contact with the station placed at the ground. This loss of contact happens mainly while the drone is turning during a flight, Kavaliauskas P. et al [46] tested that for a fly height of 74 m such problem was occurring, and the solution has been to post process the data using the results coming from the mission at 100 m of altitude. Also, the ground surface material and the resolution of the image may influence the precision of the scan during the post processing [75].

2.6.2 Total Station

Calculating the volume of a pit or a pile using a total station requires mainly two or more devices. The main pieces of equipment are the station itself that is firstly placed at a known spot where its coordinate and altitude are registered. Then, one or a series of targets are located on the stockpile or inside the pit and, one by one, the total station will have to "see" each of them and register the relative position thanks to a laser beam that will bounce on a reflective material present on the target.

Total stations have generally accuracy horizontal and vertical angle of 5'' and can measure a prism distance up to 3 km with an accuracy of ± (2mm + 2ppm x D) with a speed of 0.3 s. As a survey tool may seems fast but the process of data collecting should be done manually and the operator must reach the point of evaluation to place the prism, this aspect already gives a huge disadvantage to this method because not always the solution of sending an operator to the measure point is considered as a safe solution.

To explain it in a clear way, we can refer to the drawing taken from the user manual of the GTS-230N Series from Topcon.
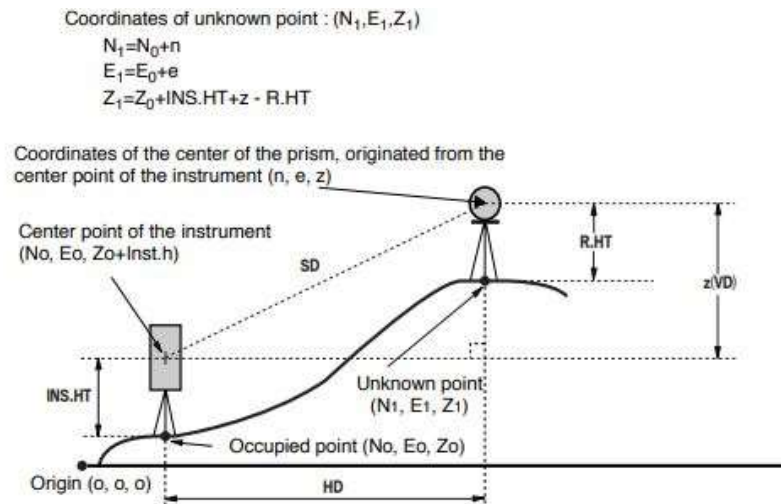
Coordinates of unknown point : (N_1, E_1, Z_1)
$N_1 = N_0 + n$
$E_1 = E_0 + e$
$Z_1 = Z_0 + INS.HT + z - R.HT$

Coordinates of the center of the prism, originated from the center point of the instrument (n, e, z)

Center point of the instrument
$(No, Eo, Zo + Inst.h)$

R.HT

SD

z(VD)

INS.HT

Unknown point
(N_1, E_1, Z_1)

Occupied point (No, Eo, Zo)

Origin (o, o, o)

HD

Figure 27 Total Station Geometric setup - Reference [7]

After the acquisition of all the planned points we should process them in a calculator and then we can get, as a result, the actual geo position of the acquired point.

This procedure requires a very large amount of time and to speed it up the surveyor may need additional co-workers. So, this approach is not a good candidate for periodic surveying.

2.6.3 Total station with GNSS RTK

This method also requires a total station to be placed and georeferenced in site and by means of a rover handled by the professional the desired points can be mapped the two tools are connected via radio frequencies. The instrument is so composed by the total station and by a pole where the second receiver is installed. The tool that allows the user to perform the survey is a computer with a shape of a tablet with a keyboard, sim card and a camera.

The measurement time is about 5s to 10s in order to get precise fix coordinates [6]. The biggest advantage compared to the total station, and to the laser scan, is that there is no need of postprocessing to obtain the actual coordinates of the mapped point.

Figure 28 Typical Rtk Tool Set - Guidelines for RTK/RTN GNSS Surveying in Canada [8]

The result of this survey can be then exported as a calibration file or if the points are processed and then triangulated a LandXML can be created. This is one of the most diffused methods of site survey used and it requires a team of 2 to 3 people, weak point is that the operator must reach physically the location to be surveyed and not always this is safe and efficient solution.

What have been exported from the rover is than considered reliable only if the procedure of survey is performed with precision.

The same principle, receiver and possible outputs are used within the machine guidance system, so the excavator or any other heavy machinery may be used as survey robot. The tip of the excavator is the point that will be mapped

2.6.6 Laser scan (LiDAR)

Light Detection and Ranging is a system capable of scanning objects by mean of laser to produced three dimensional discretely sampled surface made by a cloud of points that have X, Y and Z coordinates. By georeferencing the tool, each point can be linked to the exact longitude and latitude. The data coming from the scanning procedure are then collected and processed by the computer to create meshes or solid model. Laser scanner allows the generation of high-resolution digital surfaces models (DSM) and after post processing the digital terrain models (DTM) the two models differ from each other by the presence of vegetation or manmade construction within the first one.

This device can arrive to 2mm range accuracy, a minimum and maximum range respectively 0.6 and 120 m (Values according to TLS Faro 3D 120 with 70-megapixel colour digital camera specification). These devices are able to be georeferenced and thus the resultant point cloud data will be georeferenced as well, the extension of a

point cloud data file is a .gmd which can be processed by Autodesk Civil 3D while Autodesk Revit will accept it if translated as point list as .txt.

LiDAR approaches have three methods that are time of flight, interferometric, and active triangulation. Most common for 3D object scanning are Time of flight and active triangulation.
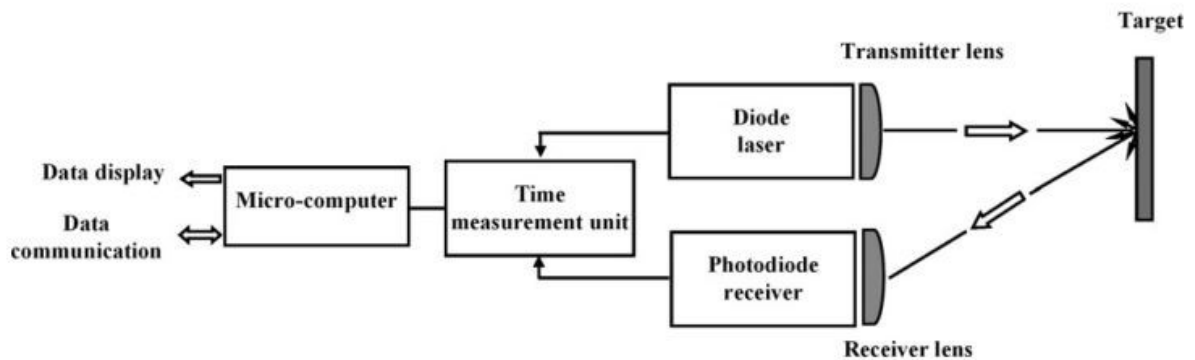
Figure v- TOF method

The fields of application are many such as industries, arts, maps creation and engineering. Nowadays companies are introducing more and more sophisticated devices to help engineers to create a 3D model of the as built constructions. One of the most innovative solutions comes with the integration of a laser scanner within a total station, unluckily these products are mainly used for topography studies

This equipment can provide precise points useful for the creation of the digital terrain model, but they require a strong post processing. The cost of rent or purchase of the whole instruments can go up to 30 thousand euro or more, so they are relatively expensive. Furthermore, they require specialized technician. They may be influenced by atmospheric condition or visual obstruction. Carrying the survey require also planning and additional workers, so this opens a question mark if during the excavation phase is possible to have frequent surveys. For this reason, a different method for acquiring "as built" condition in a more cost-effective way should be studied.

2.6.5 Summary of the tools analysed

After browsing the possible survey tools, it is prepared the table below to compare the main properties and aspects of the options available.

The comparison considers: the speed of a complete scan of the site, the difficulty considering post processing and tool usage, the amount of data that the tool will produce in terms of file weight and entities creation, weather dependency in terms

of visibility/wind, special aspects proper of the tool and the output that we could get after its application.

Tool	Site scan speed	Difficulty	Amount of data	Weather dependency	Special aspect	Output
UAV	High	High	High	Yes	Driver need license and possible additional flight permits or limitations	Cloud of points
Total Station	Very low	Low	Low	No	Requires time for target positioning and aiming.	Points
Total station with GNSS RTK	Medium	Medium	Medium	No	The total station is kept in contact with the positioning system and can acquire more data than a regular TS	Points
LiDAR	Medium/ High	Medium	High	Yes	Scan of portion of the site and requires data post processing. Initial cost of the equipment is very high	Cloud of points

It is important to mention that trough out the literature available on the scientific database there are many examples of innovative ways of using the presented tools. Soonwook Kwon et al. [54] experienced an hybrid scan method by using LiDAR and UAV imagery that sees the overlap of a 2D cloud of points coming from the drones and the 3D one generated by the laser scan. Such approach sees a high difficulty on data processing but the accuracy make it suitable for further application of augmented reality and Ais.

Considering that all these tools are used during surveys activities, this thesis wants to study the possibilities of replacing them by using the outputs coming from the machine guidance technology.

2.7 Machinery integration

Lately on the body and cabin of the earthwork machinery many technological instruments such as sensors, tablets and measurement instruments have been added increasing the complexity and precision of the apparatus.

To full usage of such equipment is given by the "machine guidance" system and the creation of productivity reports. In the following paragraphs it will be presented the actual technological situation for an excavator with machine guidance with GNSS RTK.

2.7.1 Sensors

Many sensors can be added to the machines. A full and functional set is defined by installing GPS antennas, radio receiver, modem, cameras, IMU, central processing unit and a display in the cabin for the user interface.
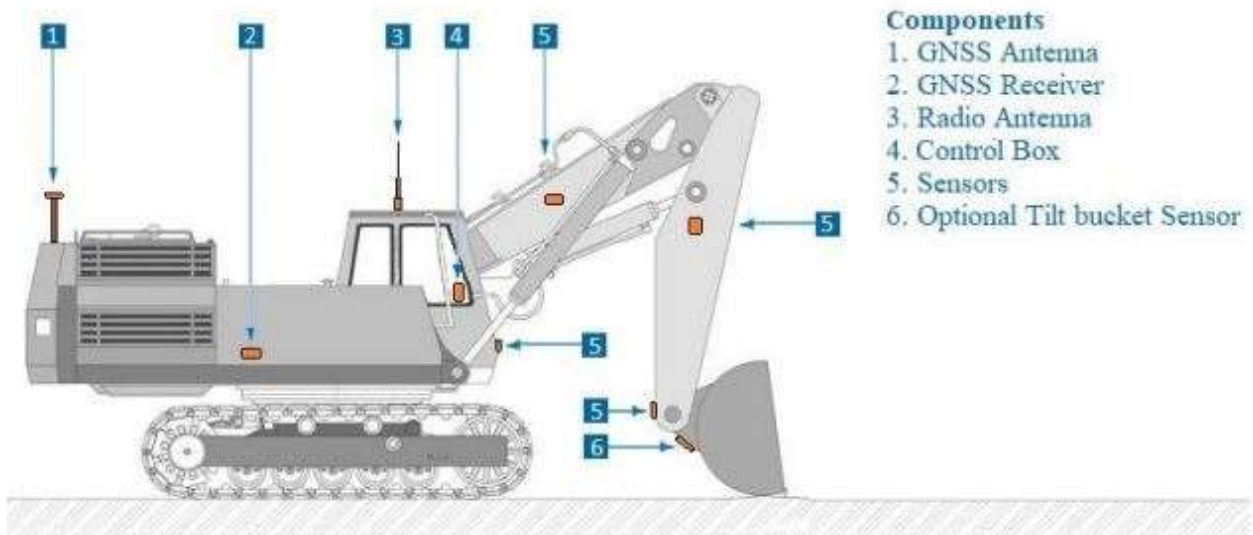

Components
1. GNSS Antenna
2. GNSS Receiver
3. Radio Antenna
4. Control Box
5. Sensors
6. Optional Tilt bucket Sensor

Figure 29 - Additional equipment mounted on the excavator - [24]

The boom, stick and bucket are equipped with the IMU sensors that are able to analyse the movement and all the quantities related to the cinematic of the arm. An inclination system is then added to correct possible error while defining the position of the excavator.

2.7.2 Positioning devices

The Global Navigation Satellite system is integrated within the machine by adding antennas on the body of the heavy equipment or on poles attached to the bucket of the dozer

GPS antennas works with GNSS system and can be upgraded by adding RTK technology to improve the precision. The retrieved position is always referred to the position of the blade for the case of excavators and dozer.

IMU (inertial measuring units) have been integrated on the stick, boom and on the bucket. After being calibrated in factory they can define angles, movements and weight associated to the task that is being performed.

Radio receiver is then used whenever the position of the equipment is referred to a base station already calibrated and constantly present on site.

A modem can be used instead of a radio to use refer the position of the machine according to a network of VRS (Virtual Reference Station) installed among the country land. It used an internet data exchange, and it doesn't require anymore the presence of a base station.

Cameras are mainly used to allow the user of being aware of the surrounding.

An alternative for the GNSS system is identified the UTS. It doesn't require to "see the sky" since it works by means of a total robotic station that can follow just a single machine using keeping visual contact with a prism positioned on the machine. It requires to be preliminary positioned in a known position of the site to know constantly the position of the blades. It will be not furthermore analysed since in this thesis we will refer only to main constructions sites placed above the surface.

Pros

The described system relies on satellites that are always available to exchange data with the machine and whenever is used a double antenna the position of the blades is always known. Compared to previous 2D systems it just requires to be calibrated only once.

Cons

GNSS system always require the machine to be able to "see the sky" since it works by using the four available constellation such as: GPS, GLONASS, Galileo or BEIDOU. Also, it always needs at least 4 satellites to assess the real position with a 15-millimetre precision.

3 State of the art of the process

3.1 Actors Involved in BIM oriented construction projects

The RIBA institute defines the overall works stages of a construction project into eight phases, where the construction per se takes place at the beginning of the stage five until the end of stage six. Such definition is contained into the RIBA Plan Of Work [73].

The eight stages are then listed below [72]:

0. **Strategic Definition**: where the client's business case and strategic brief are assessed to ensure they have been properly considered and the scope of the project is defined.
1. **Preparation and Brief:** developing of initial project brief. This considers the feedback from previous projects, the definition of spatial requirements, carrying out surveys and quantifying the budget. It is performed a feasibility study, a risk assessment and the team is assembled
2. **Concept Design:** here it is produced the design concept, cost plan, buildability, concept of architectural/structural/services design. For the case of BIM project, the built asset can be represented by massing diagrams or 2D symbols that represent generic elements. The project information model can also include drawings reports and other structure information [74].
3. **Developed Design:** The RIBA described the activities carried out during the stage as preparing the developed design, including co-ordinated and updated proposals for structural design, building services systems, outline specifications, cost information and project strategies in accordance with the design programme[72].
4. **Technical Design:** at this stage the preparation of all information required to manufacture and construct a building is performed.
5. **Construction:** this stage may also include, demolition, rebuilding and alterations of existing buildings
6. **Handover and Close out**
7. **In use:** here is included the activities of letting, rating, maintenance, Energy consumption (and certificates), insurance and so on.

Above all these phases we can define the process of control that is constantly present to ensure the quality of has been done. The BIM approach is meant to be integrated among all the building process and therefore it creates new types of occupations within the process.

We can describe the traditional process as a linear approach where the next task can't commence until the previous one is finished, and consequently the procedure of clash

detections is done usually during the executive phase. Upgrading to the BIM method it is required to update software, hardware and organisational culture [25]. As shown in the picture below it is presented by Almutri (2016) the difference between the traditional approach and the BIM approach throughout the project phases. In the traditional method the impact occurs at the level of construction documentation which is then solved by using a BIM approach in the early stage [26]. Also as reported by Ashraf Elhendawi [25], the traditional methods suffer from many issues such as lack of project understanding, poor communication and data loss, problem in sharing information and poor collaboration between team members.
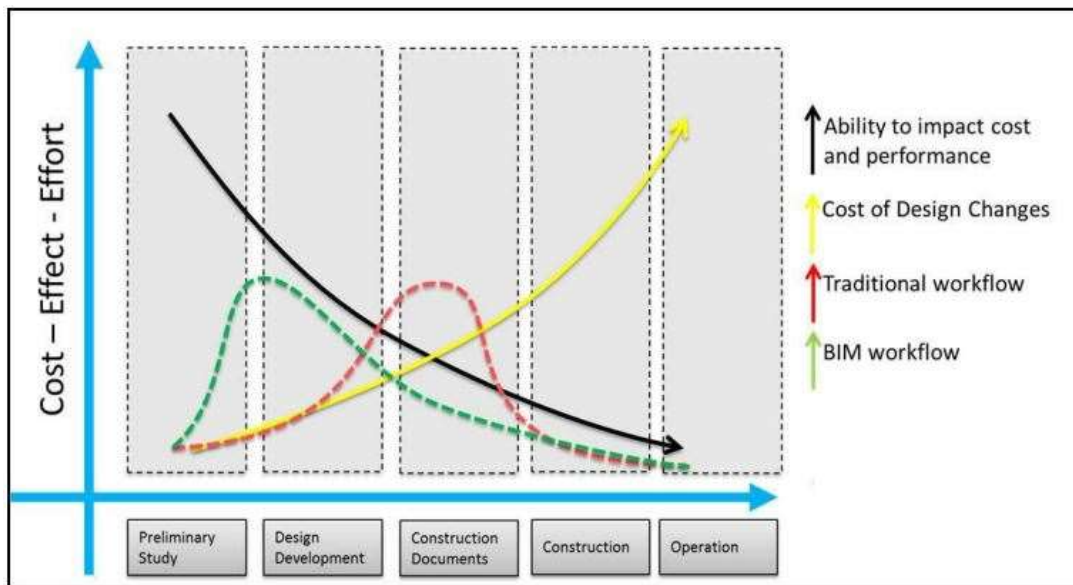
Figure 30 - The value of BIM for the design proces - [26]

So, sharing data requires a database and a person that can manage such environment.
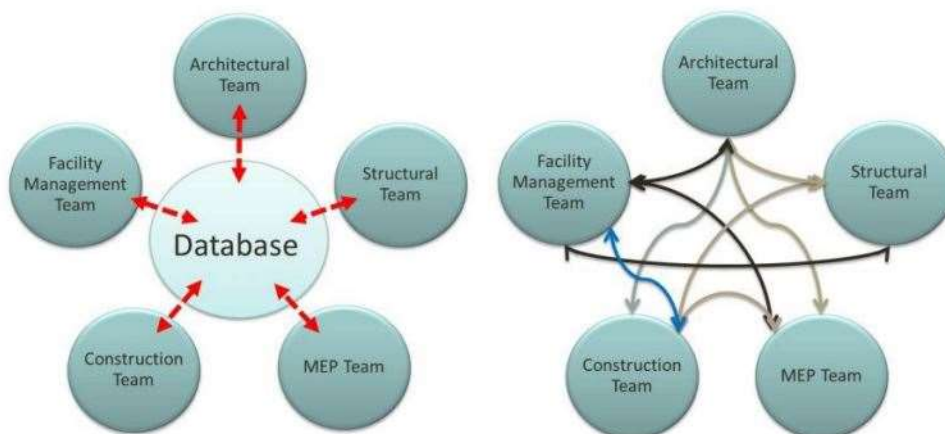

Figure 31 - Difference of data sharing between traditional and BIM approach - [25]

Before presenting the actors considered it is expressed as a diagram the main figures identified by the ISO 19650 Teams and Parties. Where below the terms architect,

engineer and sub-contractors are also, for example, respectively meant figures like: interior designer, structural or electrical engineers and as sub-contractors the material providers and so on.
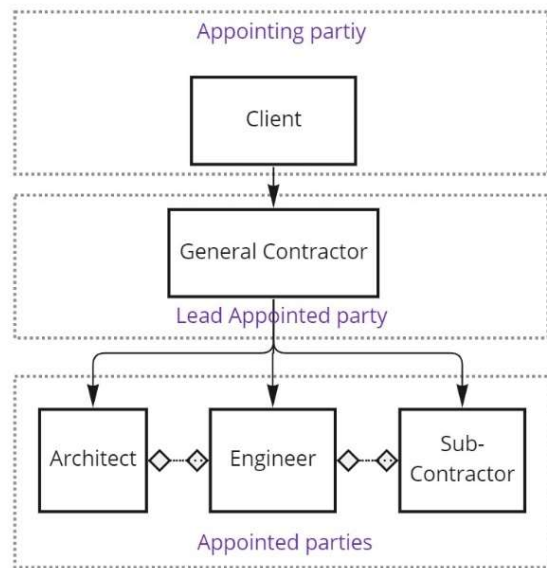
Where the appointing parties can be seen has the client that wants to start the process to build an asset, with the consequent requirements. The lead appointed party is appointed by the client and can be one or many. Then the appointed parties can be divided into task teams that are responsible for specific tasks [52].

3.1.1 BIM specialist

Inside the category of a BIM specialist, we can see different task that he can cover, Ashraf Elhendawi [25] provides the following definitions:

- BIM modeler, create and develop the 3D BIM models used to extract 2D document documentations
- BIM analyst, perform simulations and analysis on the given model
- BIM facilitator, is addressed to assist other professionals such as foremen or constructors, in visualizing model information and assisting the engineering work
- BIM consultant can be hired by companies that does not have experienced expert to be art of the project team. The consultant can be strategic, functional or operational
- BIM manager is the responsible for coordination, control, development and updating BIM model. He deals with project information and actors involved. He is addressed to manage the BIM models coming from the various disciplines

and he merges it into a master model that will be used for checks of the designed and as-built conditions.
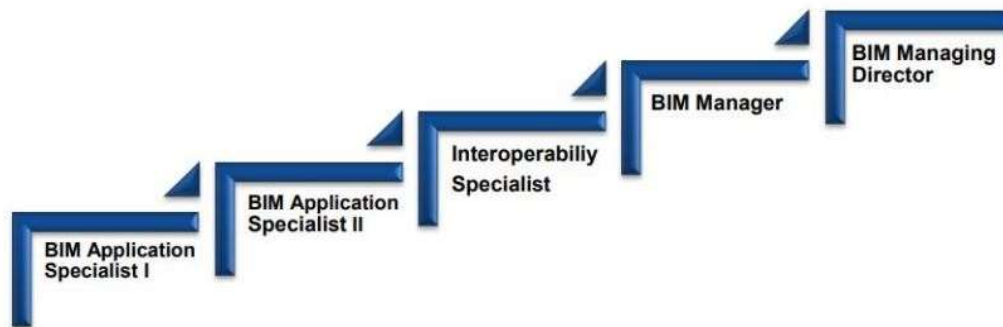

Figure 33 - BIM corporate support team Ladder - [25]

Going back now to the earthworks project actors we can define the occupations required to fulfil the tasks. For the following definition I'll refer to Persson (2018) [24]

3.1.2 Site Managers

Are responsible for the production at a construction project. Their responsibilities are planning, economy, execution and managing of the staff and subcontractors. Also, they are responsible for the quality of the project works. They are legally the representative with responsibility for works and personnel as well as for the economy [24]. For public procurements, during the phases of design, designation and execution of each process a RUP (Responsabile Unico di Procedimento), chosen by the procuring entities before the preliminary phase, should always supervise. Such actor is responsible for the correct execution of the work in relation to the quality, time, costs, safety of the workers, programmed maintenance and laws. The RUP should be an experience person that owns an adequate level of knowledge and with an experience of at least 5 years. For work below 500.000 € the RUP can be also coincident with the figure of works manager.

The Construction supervision should be formed according to the dimensions and category of the work. the works manager has the responsibility of the whole Construction supervision team, and he should perform a control over the technical, accounting, and administrative aspect during the execution of the site. He may be helped by a series of executive directors that helps him during the supervision of the activities.

Then an executive safety coordinator should be chosen if the Works manager is not enough qualified to cover such position.

3.1.3 Construction engineer

His duty is to support the site manager, he shares responsibility with the Site Manager of the project management and economy monitoring of the processes. He provides calculations, final reconciliations and cost follow-ups, creation of changes, supplementary work, documents management and administrative works [24].

3.1.4 Supervisors and surveyors

Supervisors are subordinated to the site manager and are responsible for the daily or weekly production, they usually control machine and material and ensure that the as-built condition follows the designed project.

In terms of safety are instituted the figure of the CSP and CSE that are correspondently the coordinators of safety during the design phase (CSP) and executive phase (CSE). The CSP during the design of the executive phase participate to the creation of the PSC (safety and coordination plan), provides reports where it is contained all the knowledge in terms of risk prevention and assessment link to the process, collect information about the site in which the construction will take place and actively intervenes within the design decision, with the purpose of reducing or eliminating the risks [44]. The CSE during the executive phase will ensure that what stated and planned within the PSC is followed, update/modify the safety plan according to the working conditions, report of works not compliant to the law, help the coordination among the appointed parties and reduce the risks linked to the simultaneous or consecutive presence of worker within the site.

Surveyors are addressed to perform on site measurements to keep tracks of the built objects and consequently update the drawings representing the as-built condition. Their work is crucial for keeping track of the productivity [24]. The machine guidance system with mapped point may be used to limit the cost and time spent for surveying the site. The need of improve such technology can give great advantage to the productivity of an excavation process. It is so required to produce reliable mapped data that can be used lately for automatic drawing and quantities updates.

3.1.5 Construction workers and machine operators

Construction workers are on the executive side their work includes a wide range of tasks for example: laying pipes, cables, perform foundation work and assistance to the machine operators [24].

Machine operators play an important role, they may use different types of heavy machinery to fulfil the purpose of the design. The quality and speed of the work done

depends highly on their skill and capabilities, also the amount of data registered by the machine depends on the number of steps and rework that they need to finish the assigned task. It is so, highlighted the need of finding a proper work procedure to reduce the impressions generated by the data coming from the machine. For example, it is common that a machine operator may forget to switch off the machine guidance system while performing other activities that are not linked to the excavation process or if the machine encounters any problems in georeferencing the worker continues to dig without so retrieving any data. In conclusion, the overall surveying of the process relies considerably on the machine operators.

3.2 Designing an earthwork project

The core of the earth movement technique remained essentially unaltered during the past years, this because the main goal of the process is following the cut and fill workflow. But this is how it looks like if we look at the process from a distant point of view. During the last decades the improvement of the technology allowed the designer, the project manager and the worksite operators to work in a safer and precise manner. The systems integrated within the machinery and the development of new software may open the possibility of improving such process.

3.2.1 Project Development

In first place the engineer decides what is the final levels curve that will be reached at the end of the excavation process, in this way is possible to understand the amount of volume of earth that will be moved. The choice of the dimension of the interested area is defined accordingly to the scope of the excavation. Types of work usually are:

- excavation for realization of slopes or foundations
- Set section trenches for plumbing or precision works
- Embankments or cuttings for road, tunnel or railways realization
- Compaction of the soil for construction site path or finalizing the surface
- Truck loading
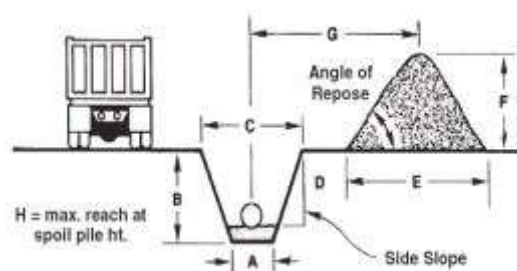- Removal of vegetation or "scoticamento"

Figure 34- Set section trench example

To realize a building most of the previous type of excavations will be required, and consequently different type of machinery will be inserted in the fleet. To give a better understanding we should define the different kind of powers that should be analysed in the design stage.

- **Power** is the ability of doing work in a specific period, it can be represented by the horsepower of the engine and so the hydraulic power of the machine.
- **Required Power** is what is asked to be able to win the resistances acting on the machine in order to perform the task required
- **Available Power** is the one developed by the machine while performing a specific task.
- **Useful Power** is the one available under specific working condition

The process of earthmoving usually comes at the beginning of a construction site so, its operations are mostly listed at the beginning of the WBS (work Breakdown Structure) with the phase of construction site settings.

At this stage of the project is necessary to plan the type of work in a chronological way and forecast the amount of time that is required for the tasks to be completed. Is important to have a clear idea of the times and volumes that the work will require, in this way is possible to choose the power of the machinery and the dimension and type of tools that will be used. To define if the proper machinery is chosen the following aspect should be analysed:

- Time for a full cycle
- Production
- Compatibility of the choice of machinery
- Choice of the right tools

To dimension the machinery needed it should be used the handbooks given by the producer of the equipment.

3.2.2 Excavation Process

At the very beginning is necessary to define the soil composition within the area in which the building will be constructed and along the depth in which the excavation process will be taken. This step is usually performed by a geologist that through a study of the existing data or by mean of core drilling can assess the type of material that will be encountered during the excavation process. Then is required to collect data regarding the morphology of the terrain and the condition of excavation. We can collect all these operations under the definition of "surveying activities". Then is necessary to acquire the mandatory permits to perform excavations work and for the

waste disposal. It is important to forecast accurately the volume of waste and the volume of earth moved in order to have a precise estimation of the costs and time. At this stage the DTM created with a BIM approach is fundamental. The 3D level of the BIM linked with a volume estimation between the surveyed surface and the final project situation can be modelled precisely by dividing it in phases. The phase division is important because it will automatically create a series of expected checkpoint that will become useful to estimate the quality during the process. The bill of quantities is nowadays easily handled by the software once is set.

Then, the first step before excavating is the cleaning of wastes and subsequently the galling of the surface where the layer of vegetation lies. According to the type and quantity of the material that must be removed, is possible to choose among man work power or machinery. The machineries that are usually linked to this type of work are:

- Excavators, equipped with buckets or special tools
- Wheel Loaders
- Dozers
- Dumper or trucks, also for transport outside of the construction site

The process of cleaning can be only represented as a virtual process, while galling is exporting the first 10 or 20 cm of terrain from the site so it can be then included in the 3D representation for an automatic QTO. It should be then included a possible crush or explosion of rocks which sees the usage of special equipment (e.g., hammers) on the excavators or the employment of explosives.

Next, there is the excavation process which is the main step where most of the volume is moved. If no machine guidance is used, the traditional process sees the operator of the excavator following the lines traced by the topographer (or the designer of the excavation pit) on the ground and with frequent surveys of another operator to check slopes and depth. Many years until now the excavators are commonly equipped with at least a 2D machine guidance system, except for the mini excavators. This technology considered now as default is like the 3D guidance system, it can guide the operator to the correct positioning of the bucket tip to follow the pit design, but it differs to the 3D GNSS RTK with because it needs to be set every time the machinery moves, so is still a manual setting that the operator must deal with once he decides to move from the current position. If 3D guidance system is used, the project will be of course uploaded on the tablet on board and the machine will be calibrated. With this system wherever the operator will drive the machinery it will be always located by the satellites giving him the guide of the excavation to perform. Is useless to say that is already stated that this technology is increasing the productivity, reducing the

costs, reworks and consequently reducing the fuel consumption. But nowadays even with this technology the survey of the as built condition is still performed by the engineer on site. Excavating is always divided in cut and fill so we can define these two processes as a positive and negative variation of the volume present on site, usually to fill is used some previous excavated soil that have been stored previously on piles. This opens the management of stockpiles in a convenient place that will ease the accessibility in a safe way. During the overall procedure is usually forecast the maintenance of the road inside the construction site such as wetting or compacting, is necessary to ensure a constant efficiency of the movement of the machinery and to reduce the quantity of dust that is produced overall. Another type of excavation is linked to the placement of plumbing or specific punctual elements, we refer to this process as trench excavation, it requires precision and accuracy in the design phase.

When extracting the soil its volume will increase, so we refer to this as bench and loose volume, this happens due to the loss of compaction once the material is exported. Is important to refer to special coefficient related to each type of material, whether is fine or coarse, and it allows to design the dimension of the stockpiles. Furthermore, once the material is filled back it will still require compaction and the quality of the process is then tested thanks to pressure plate tests. Finally, is the transportation of the resultant material, in this phase trucks or dampers are carefully chosen according to the productivity of the excavating machinery. Dimensioning of the truck capacity must be studied to reduce the idle times and to ensure that no overweight tracks will roam the public road and bridges. For this purpose, a weight scale is mandatory for the trucks coming out of the construction site.

3.2.3 Volume of material moved surveillance

Nowadays the quantity of material moved during the excavation process is checked using periodic surveys. Such operations are performed in site by the surveyor in charge, chosen during the design phase. The method that generally is used consists in taking specific points of the pits and piles using a rover connected to the satellites. In the last year some professional moved to the usage of drones or laser scans, but for the reasons already discussed in the previous chapter is still not widely used. Then, after the survey operations the engineer processes the collected data by updating 2D drawing of the sections or by creating a new DTM to be used for comparison, for productivity study, with the initial state or for time remaining surveillance with the designed profile. Usually, this method requires time and money and in the case of very productive site the report given after the survey will result being out of date.

According to Kavaliauskas P. et al [46] within their study they stated that a conventional survey activity performed with a rover connect to VRS will take a full working day of a professional surveyor for site 2D area of 5549,55 m^2 where are collected points approximately every 10 to 15 m. The volume that was evaluated is 10'532.21 m^3 including 16 stockpiles, the speed surveillance, if we consider 8 hours of work is 1316,5 m^3/h.

3.2.4 Cost surveillance through the model

The cost surveillance in a site that uses machine guided equipment is done in a more automatic way. The costs that are checked are the:

- The operator salary related to the time of employment
- The fuel consumed
- The eventual cost of rent of the equipment

These parameters can be easily checked thanks to the report of the machinery and thanks to a previous organisation of the working schedule. The main problems comes when, for larger sites, the fleet is composed of many machineries doing different works such as not excavation related work or maintenance of the roads. This last aspect can be eased by proposing an integrated approach where all the equipment is connected and checked within a single and well-prepared model.

3.3 Classification systems in Construction

As mentioned in the chapter regarding the BIM intended workflow, the concept of interoperability is one of the core points of the approach. To fulfil this requirement is important to remain consistent within the naming of the physical and abstract elements composing the building and the entire design/executive process. The international standard ISO 12006-2 is the standards that regulates the content of a classification system. It shows examples of classes that can be subjected to classification such as, management activities, construction agents, products, process, entities, etc. Some examples of classification system based on the ISO 12006-2 and used for BIM applications are OmniClass, Uniclass and the Italian UNI 8290.

For the purpose of this thesis, we will focus on presenting the OmniClass and UniClass since are more focused on activities and QTO, while the UNI 8290 is more useful for coding technological component of the buildings.

OmniClass

From the CSI website we can get the self-definition of this system [36] *"The OmniClass Construction Classification System is a means of organizing and retrieving information*

specifically designed for the construction industry". It is an American standard that ensures completeness also comprehend the specification of MasterFormat 2004 (for work results), UniFormat (for the elements) and EPIC (for the products). It can be considered as an implementable open system. From the website referenced as [36] it is possible to understand that the whole classification system is organized by a total of 15 tables that can be grouped by topic as follow:

Topic	Number of the tables
Organization of the results	11-12-13-14-21-22
Representation of the construction processes	31-32
Organization of the resources	23-33-34-35-36-41-49

The code is composed by a prefix number that declares the table number and by four couple of numbers that represent the level of the information, from a higher to lower, the level 4 is the more detailed level, see screenshot from table 22.

Figure 35 - Sample of codes according to OmniClass table 22

Using this classification system, it is ensured that is:

- Public
- Integrable
- Expandable

UniClass

The Unified Classification (UniClass), developed by the NBS (National Bureau of Standards), is another classification system that is used for the Britannic industry, it is equivalent to the already explained OmniClass, it also refers to activities and spaces,

which is the key point for developing a WBS for earthwork purposes. This system is developed following the ISO 12006-2:2015 and is strong feature is that it unifies the coding referred to the buildings, infrastructures and environment. It refers to the components with a more common terminology and it is flexible for further expansions.

It is organised with a series of tables that can be used to classify:

- Bill of quantities
- BIM object definitions
- Documents content
- Management topics
- Maintenance
- QTO
- CAD layers

And many other activities and objects. The tables that are present within the standard are:

- Complexes: describe the function of the building (School, Residential, …)
- Spaces: are physical area in which can take place different activities
- Activities: represent the activities to be carried out in a complex or a in an entity, this tables includes also investigations and maintenance [43]
- Entity: it identifies the parts or areas of which a project is composed
- Elements: are the technological components of a structure (wall, roofs, …)
- Systems: parts that compose the element (eg. External wall has, structure, insulation finishing and so on)

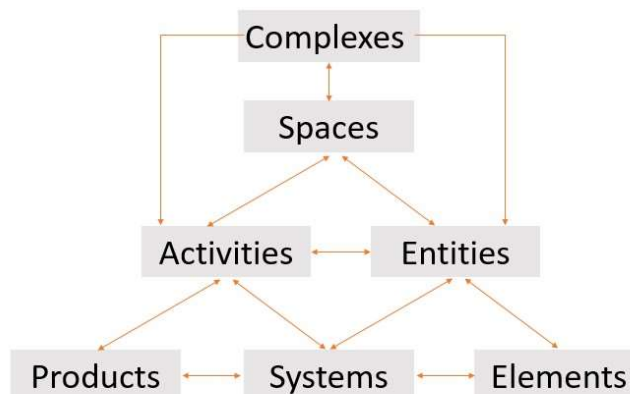The organisational hierarchy of these tables is as follows.

Figure 36 - Uniclass tables hierarchy - [43]

The code is composed of four or five couple of characters:

- First couple: composed by letters identifies the referred table
- Second couple: made by numbers refers to the group
- Third couple: identifies the subgroup using numbers
- Fourth couple: also made by numbers refers to the section
- Fifth couple: again, constituted by numbers identifies the object

Coding all the elements within a project ease the filtering and selection of certain components for further analysis or checks. During the life cycle it is possible to find where a specific object or material is located facilitating so the maintenance procedures.

As the OmniClass this schema is not mandatory so it should be used only after an agreement within the actors.

To implement this standard within an IFC exist BIM viewers that can automatically assign the correct ID by referring to the standard with the entity IfcClassifcationReference and IfcClassification [43].

3.4 Documents
3.4.1 Traditional documents

The most complex case of an execution of a construction site is the public work. In Italy the law framework describes in detail the procedure that has to be followed and the documents that the actors must produce. The contractor will create a tender that can be:

- Open: any economical subject can join
- Limited: The Appointed party are previously selected and are invited to the tender. The producer can ask to be invited if is compliant to the limitation imposed by the client.
- Negotiated: when the appointing party is choosing the general contractor and the conditions are discussed
- Competitive dialogue: is a procedure chosen for particularly complicated cases. The admitted candidates are asked to cooperate to find one or may solutions that are suitable for the needs imposed by the client.

The custody of the tender is performed trough open or limited procedure and it should be proposed a preliminary project with all the documents and report that are useful for the technical and economical evaluation [44].

The regulation framework acting in Italy is very large and it is composed by Italian and European code that have been subsequently translated into laws.

Initial documents

The type of work must be evaluated in order to understand the permits that should be obtained. Survey documents has to be produced such as geological, geotechnical, seismic and hydrological inspections. An initial estimation of the cost is also necessary. All the preliminary documents should aim to answer to the needs and requirements of the client.

Accounting documents

The administrative and accounting documents are the following:

- Diary of the works
- Books including the measure of the works and materials
- Weekly lists
- Accounting register
- Summary of the accounting register
- The SAL (stato avanzamenti lavori) is the as built condition
- The certificates for payment of the instalments
- The final bill and additional report

Thanks to the reference [44] it is possible to link the actor and the documents that is responsible for.

Document	Responsibility		
	Work Director	RUP	Client
Diary of the works	X		
Measures books	X		X
Weekly lists			X
Accounting Register	X		X
Summary of the accounting register			
SAL	X		
Certificates of payment		X	
Final bill	X		X
Report over the final bill		X	

Safety documentation

The European committee stated that safety is positively influenced by a correct plan during the design phase, so they proposed changes into the procedure rather than the introduction of new technical rules [44]. They intervened specifically over the figure of the appointing party and of the coordinator of health and safety for both the design and execution.

The main document that must be produced is the safety plan and coordination, PSC (Piano di Sicurezza e Coordinamento) that includes all the documentation needed for safe planning of the operations and summarize the costs linked to safety. The document is containing the risk assessment linked to the site area, the processes, the tools and the machine that are involved in the overall construction and is then completed by the site layout drawings, the costs related to safety and the time plan of the operation with the relative clash and overlaps. As already mentioned in the paragraph about the supervisors, the PSC is created under the surveillance of the CSP and its application is ensured by the CSE.

3.4.2 BIM documents and regulations framework

European directives 2014/23/UE, 2014/24/UE and 2014/25/UE for the digitalisation of the construction industry focusing on public tendering have been introduced on the 26 of February 2014. The countries that are part of the European Union are then delegates to reference the directives within their own laws. In Italy the law n. 11 of the 28 January 2016 refers to the valorisation of the public tendering by improving the architectural, technical and functional quality by progressive usage of computer aid tool for informative modelling. The DLgs 50/2016 "Codice dei contratti pubblici" at the article 23 states that the appointing parties may ask for the use of specific electronics tools for new construction or refurbishment with the priority for the more complex works. Such tools must be interoperable platform that export in non-proprietary format. The DM 560/2017, now modified with the new Decree n. 312/2021, within its article makes effective what said into the article 23 of the DLgs 50/2016 and states that the client should provide a plan for the training of the staff, a plan of acquisition and maintenance of the hardware and software used and organisational act that will explicit the process of control and management of the data and conflicts. Moreover, under the article 4 it is expressed that the interoperable platform should transfer data among a common data environment in order to optimize the data flow and to ease the decisional processes.

The ministerial decree establishes the years and conditions in which the usage of such tools will be mandatory. The conditions are referring to complex works and their

tender based amount. The table below shows the time and values in which the law will apply.

Tender based amount (millions of €)	Period of implementation
≥ 100	2019
≥ 50	2020
≥ 15	2021
Amount equal or higher compared to the one expressed in the article 35 of the DLgs 50/2016	2022
≥ 1	2023
< 1	2025

By this table is possible to notice how the progressive implementation of the BIM approach will bring to a mandatory usage after the 2025. The aim of the European Union is to enhance the interoperability between the actors involved in order to achieve precise projects that can be correctly evaluated by means of simulations and feasibility studies before the construction phase.

The DM 560/2017 establishes a new document to be attached while presenting the project to be contracted is presented, the informative specifications. Contents of this document are:

- General and specific Informative requirements that are suitable for the level of detail of the project (preliminary, definitive, and so on) and
- The informative model regarding the condition of the spaces and eventual pre-existing structures.
- The useful elements for the identification of the requirements of the production, management, exchange and archiving of the informative contents.

As integration to the decrees there are the voluntary regulations that are introduced by the UNI (Ente Nazionale Italiano di Unificazione), CEN (European Committee for Standardisation) and ISO (International Organization for Standardisation). The ISO 19650 is cooperating with other regulations to define the correct management of the built environment, such as the ISO 9001 for the management of the organisation in terms of quality management, the ISO 55000 and the ISO 21500.

According to the ISO 19650 there are two main phases of an asset, which each of it has an assigned model. The Delivery phase comprehend the time span where the building is designed constructed and commissioned [51], at this stage we talk about the PIM (Project Information Model) that is contained within the Common Data

Environment and it will contain all the information that the appointed party will provide during the development of the project. The operational phase is defined by the code as the part of the life cycle, during which an asset is used, operated and maintained. At this stage we encounter the Asset information model (AIM) that contains all the information that the delivery team gives to the appointing party during the handover after a completion of the project [52].

Last but not least, the PAS 1192-2 2013 states that the appointed party should provide a plan that they intend to follow in order to fulfil the requirements of the appointing party described into the Employer's Information Requirement (CI). Such document, that have to be presented during the initial phase of a tender, should contain all the technical specification such as: documents format, Hardware, Software, coordinate systems, LOD and so on. Second part of the document contains the management topics, for example: files naming, method of archiving, Policies and so on. In Italy the main standard that is following such document is the UNI 11337.

4 Methods and tools

In this chapter we are going through the theoretical aspect and the tools that sustain the method that will be deeper explained within the chapter five. Understanding the theoretical aspects can help to build an approach or an application (e.g., plug in) that can solve a specific problem. It will be explained the theory behind a correct triangulation of the DTM with its relative benefits, the calculation through the 3D software of the volume of the soil excavated, the dimensioning of the fleet and the setup of an efficient construction site. In addition, the functional schemes of the involved software are studied to have a clear understanding of the integration possibilities. These topics are then used to answer to the open questions related to the management of the activities, costs, time, safety and creation of a possible DTM via automatic modelling.

The proposed approach can be briefly summarized by mean of a chart that shows the flow of the identified activities.
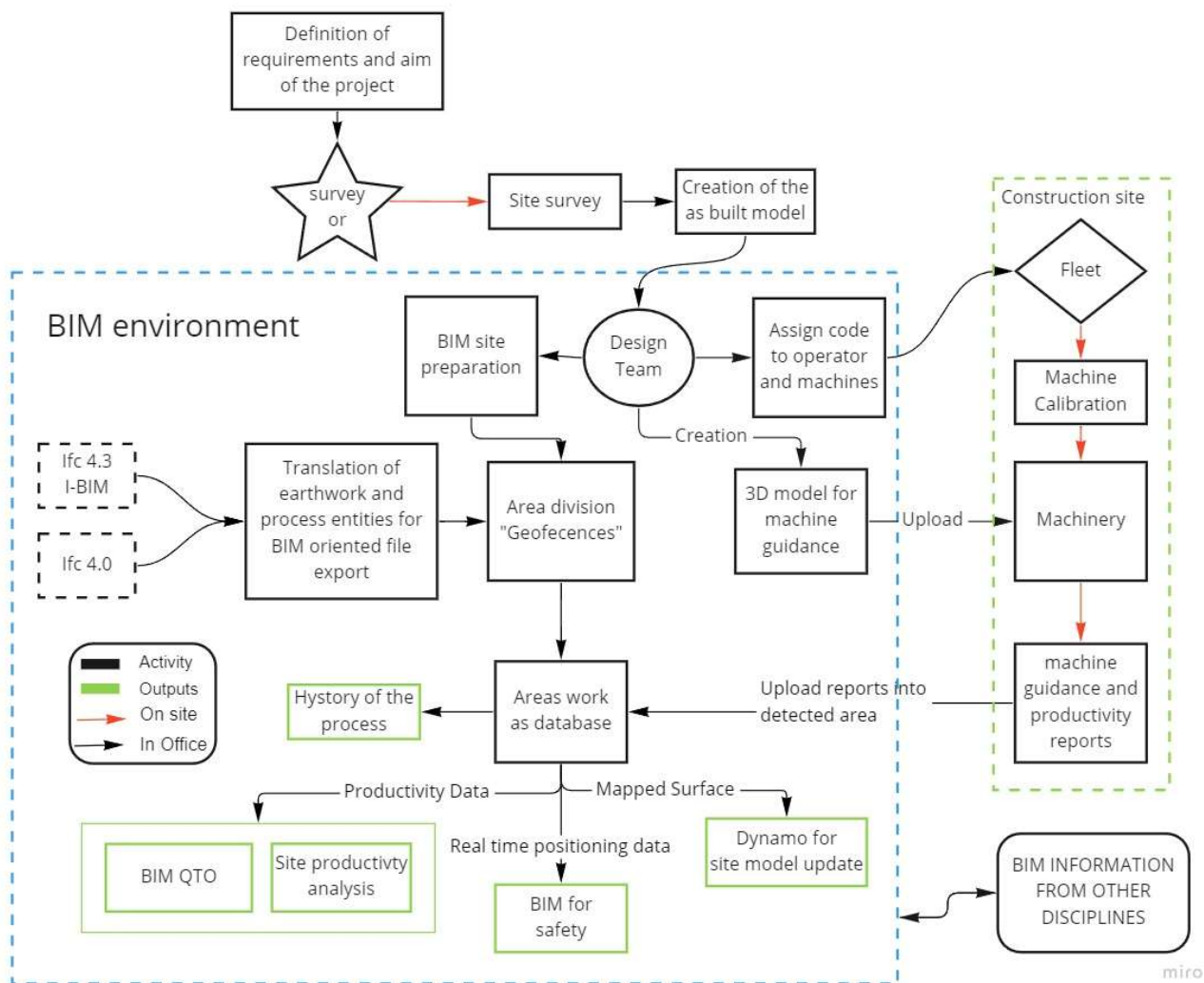
Figure 37 - Overview of the proposed method

To better guide the reading of the previous image, it is given a brief explanation. The proces studied starts from the final agreement on the requirements and aim of thw project and a first site surveillance can be performed with traditional or newer methods (UAV, lasers and so on). Then, the design team will codify all the machines, operators, areas and elements that will be involved into the earthwork operations. The fleet designed, that is fully equipped with machine guidance systems, is calibrated and provided with the proper project to follow. Meanwhile the Design team will divide the site in three main areas: roads, stockpiles and earthworks process. Such areas are then clearly defined with a georeferenced boundary. Thanks to the GIS-oriented data coming from the machinery, the productivity and the mapped points can be easily assigned within a specific area. Known the activities included within a delimited space the data can be managed and organised accordingly. At this point we can see the areas as a container (database) of the data sent by the machinery. Such information can be then kept for further studies or with the help of additional plug-in used for QTO, safety and BIM interoperability with other disciplines. As last aspect of such workflow, if well produced, the mapped points can be used to automatically update the topographical surface of the terrain model included into the BIM model.

4.1 Delaunay Triangulation

Triangulating a surface is one of the possible options to divide a surface into finite elements. More commonly in mathematic we use the term "Discretization", which is a subdivision into segments or faces of the given geometry. This procedure can be performed by the software itself if equipped with the proper algorithm and mathematical rule. So, the type of triangulation can be done according to different criteria. One of the most common BIM oriented software used is Revit, during the development of the automatic script that will be explained later in the next chapter it is tested that while performing an automatic creation of the surface from a triangulated DTM that the software doesn't accept triangles with coincident sides. Moreover, the parametric plug in (Dynamo) will consider points and sides as coincident even if they are not, but they are only very close. Solution to this software constrain is reducing the amount of point by simplifying the number of vertices, but this may lead to possible imprecisions or uncontrolled loss of data. So, using the Delaunay triangulation we are sure that no "silver triangle" will be created, theoretical explanation is given as follows.

According to Glenn Eguchi (2005) [22], given:

- set a data points $A \subset R^2$
- Height f(p) defined at each point p in A

We want to naturally approximate the height of points not in A.

A surface that is Discretized sees each face raised by the specific height of the point, so it will not look Natural, and it will create surfaces where each face boundary is located at different height compared to the one next to them. Determine a triangulation where each point of A in R^2 is a vertex of the given triangle, and then raise each of them will create a DTM from a planar triangulation where all the triangles share the boundaries [22].
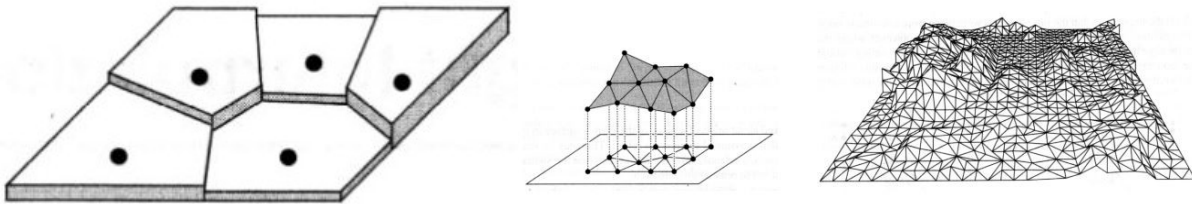
Figure 38 - Discretization (left), triangulation (right) - [22]

In mathematics and computational geometry, the Delaunay triangulation is defined as that type of triangulation where "for a given set P of discrete points in a general position is a triangulation DT(P) such that no point P is inside the circumcircle of any triangle in DT(P)." [20]. This type of geometric representation maximises the minimum angle of the triangles, avoiding so the silver triangles (triangles with very acute angles) that may cause problems in computation or representation [20]. This concept may be extended to a d dimension for n number of points, and we can list its properties according to [20]:

- The union of all simplices in the triangulation is the convex hull of the points
- The Delaunay triangulation contains $O(n^{[d/2]})$ simplices.
- Compared to any other triangulation the Delaunay will always have the maximum minimum angle, compared with the minimum angle of the other triangulation type, but this doesn't necessarily imply that it always maximises the maximum angle.

- The Delaunay triangulation is a geometric spanner: In the plane (*d* = 2), the shortest path between two vertices, along Delaunay edges, is known to be no longer than 1.998 times the Euclidean distance between them.
- The sum of the opposite angles of two triangles should be less than 180°

Is then possible to mathematically know how many faces the triangulation will have by using the Euler relation as [23]:

$$n-e+t+1=2 \text{ (Euler Equation)}$$

where:

- - n = vertices
- - e = edges
- - t = faces

A TIN surface can be based on a Delaunay triangulation and the usual algorithm of creating such geometry is performed iteratively. The software should start by including most of the points in a single big triangle and then it proceeds by creating smaller triangles and check if they are "legal" or "illegal" [22]. The term legal or illegal is referred whether the circumcircle includes or no other points. If the triangle is considered illegal the software will proceed by flipping the triangulation [22]. By flipping the triangles, they will become legal, this is due the property of the Delaunay triangulation that is still valid in n-dimensions, here below is possible to visualize what has been explained [54].

This triangulation does not meet the Delaunay condition (the sum of α and γ is bigger than 180°).

This pair of triangles does not meet the Delaunay condition (there is a point within the interior of the circumcircle).

Flipping the common edge produces a valid Delaunay triangulation for the four points.
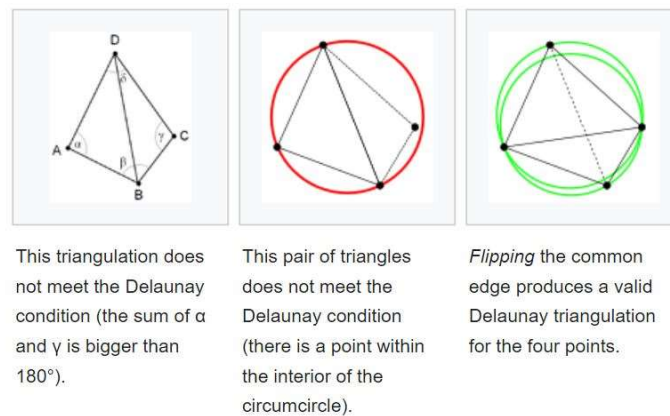
Figure 39 - angle and flipping properties - [54]

Using this Euler equation is possible to determine the complexity of the calculation during the creation of a TIN surface. It is necessary to understand the number of points contained in the LandXML file of the topographic surface or the mapped points. If the number of the points to be processed increase also the computational power of the machine should be increased, reaching than a limit set by the hardware. A complete map of a construction site can contain few hundreds of points or tens of thousands. This led to the consideration that a simplification of the results coming from the machine should be performed or the arbitrariness of the data collection should be limited by rules or specific procedures.

4.2 Software and outputs

The machine guidance technology is supported by a series of hardware, such sensors and receivers that in order to works they need algorithms and applications. The panorama of software used and available is very wide, especially if we also add the software used for design and management of the as built conditions. As we will see

in chapter 5 most of the software linked to the machinery are still not BIM oriented, so the goal is to allow the exchange of data between BIM oriented software and the ones that professionals use in common practice while dealing with such technology.

These tools handle three main categories of information that can be grouped as follows.

- Positioning information
- Drawings and design
- Productivity and processes information

All these information are logically linked to each other but still not "software-linked". The Positioning information carry knowledge useful for software that deals with drawings and productivity. These are managed mainly by the "machine side" of the software, that for our case study is mainly Trimble and CAT, but can also be any other brand, such as Leica, Volvo and others. The rush to the automatization of the processes is common among all the companies.

For the Software addressed to produce drawings and to help the design phase has been chosen to study mainly Autodesk Revit and Civil 3D since are the most common and developed. Important is to remember that also the software coming from the provider of the positioning device has integrate a 3D CAD environment, useful for design, but these product results poorly integrated withing the BIM approach.

Lastly the information about processes and productivity are not linked to specific software, the information is carried through simple spreadsheet and most of the time are managed via MS Excel or via plugin integrated in other management platforms.

Each software must be analysed to understand its potentials and its limitations and mutual bridges for information carry should be created.

4.2.1 Revit/Civil 3D and Dynamo

Among the many options of software available in the market Autodesk Revit is one of the most used for building modelling. Unluckily, we can't say the same for earthwork design which still relies on 2D or 3D CAD software such as AutoCAD. The following paragraph is developed to present the technical aspects of the software that will be taken into consideration while generating the automatic script using dynamo.

Revit

Revit was initially published in the early 2000 and along 22 years of developing it has been upgraded with additional functions, such as the adding of Dynamo (that it will

explained later). As already mentioned, this software has been widely used for the creation of 3D informative model (and digital twins) of the buildings.

The modelled objects in Revit are called entities that are collected into specific types that are further organized into families that belongs to a category. Families have parameters that are common among all the types included, the types define properties that are shared among the instances, but the instances can have specific parameter or differs from the other instances by different values of a shared characteristic. This last concept can be visualized thanks to the scheme below.
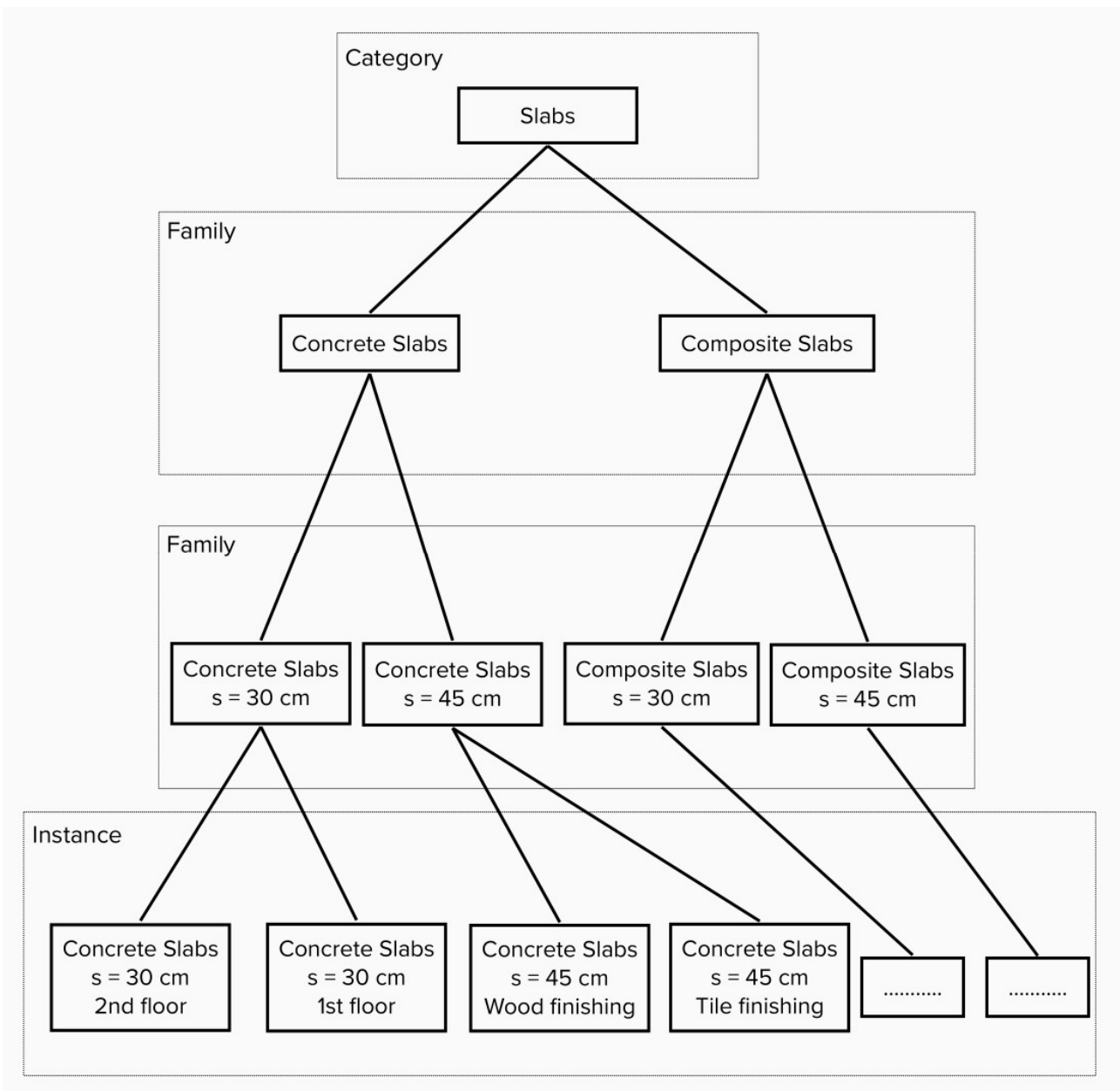
Figure 40 - Revit model subdivision

This categorization of the model makes Revit a good candidate for working with the IFC schema, it allows to interrogate the model and filter the content according to what

we would like to extract. To use the full potential of this software it is important to entry the correct data while modelling, otherwise the 3D model will be useful only for visualization. Of course, the same aspect applies to site components, areas and surfaces.

It can be said that it is the workbench for preparing the project to be then shared among the other actors and application for further analysis. Revit can handle most of the discipline such as:

- Architecture
- HVAC
- Hydronic
- Structure
- Energy
- Site

For the purpose of this thesis, it will be analysed the theory and the procedure for creating a topographical surface and to prepare the site.

The tools useful for site creation included in the Revit environment are mainly contained in the tab Massing & Site:

- Toposurface
- Surface splitting
- Subregions creation
- Site components
- Building pads
- Property Lines
- Toposurface by instance
- Creation of a graded region
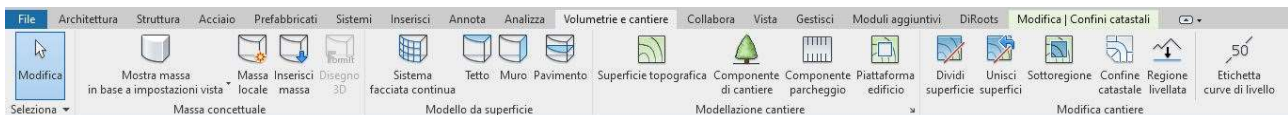
Figure 41 - Revit Massing & Site Toolbar

Adding a toposurface is usually done by adding some predesign CAD file or, for our case study, through some file containing points such as list or, if Dynamo is used, a LandXML file. It is then possible to create the boundaries of the surface, if has not been already done this step is required if we want to compare different stages in time of the surface or adding an automatic Boolean subtraction between the as built condition and the initial stage to perform a volume calculation. One huge limitation

of this entity is that the Toposurface is, of course, a surface so if we want to model the layers showing the classes of the soil (rocks, clay, and others) we should model the "Topo" as a compound layered floor using the Mass floor options, that is already included within the Mass & Site tab. If the mass is added, then we should add the properties that will be included within the IFC schema 4.3 for the IfcSolidStratum. Going back to our surface, we can now assign materials to it that will be used mainly for graphical representation. Note that if we add a section and we want to visualize it will be represented as a 3D object, but this will be still not a 3D object.

The created surface can be split to new toposurfaces, but this procedure will physically cut the existing one and will create an independent surface. The created entity can be merged and can host a different type of material, but this procedure is not always the cleanest one.

A better option can be the creation of subregions, this will not add a new entity so the file size will not increase as it was added a new one. The subregion option allows to assign different data to a specific portion of the model. The purpose of this tool is to subdivide the surface into functions or materials, allowing the assignment of instance parameters that are specific of the area.

Site components option is used as any other placing tool included within the software, according to the family that has been loaded it will follow different rules in placement and different instance or families will have already the needed parameters. If, additional parameters must be added, the designer has the power to add them within the project or by means of shared parameters. Site components are important for site organisation and space settings, since we can add temporary buildings, tools, stockpiles, machinery and so on.

The building Pads option is usually used by the BIM modeler to displace the heart beneath the building. It is an automatic command that is useful only for architectural purposes or graphical aspects.

To work within Revit and CAD software it is important to have a clear understanding of the coordinate systems that both programs use. Revit uses:

- Survey Point: Provides a real-world context for the Revit model. It can be coincident with a point taken during initial survey by the civil engineer or another team member. It can be pin, but this step will block the rotation of the project towards the True north, acquire coordinates and specify coordinates tools. It can be used during import for alignment thanks to shared coordinates.

- Project Base Point: is used within the model to establish a reference for measuring distances and positioning objects in relation to the model. It can be placed in a known spot to further simplify the on-site measurements.

Both points cannot be deleted from the file and are initially visible on the site plan view but can be additionally switched on among the other views if needed.

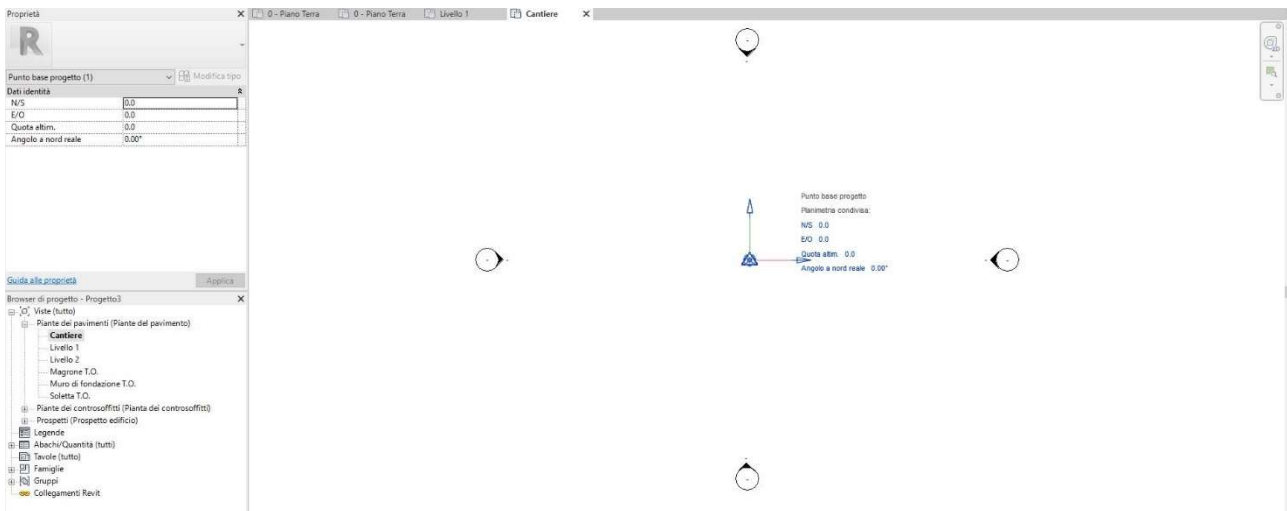*Figure 42 - Project Base point (circle) and Survey point (triangle)*

Figure 43 - Initial positioning of the survey and Project base point

Before importing the locations of the base point included in the CAD file and the survey point in Revit should be known. The linked CAD file can be then linked to the Revit model via shared coordinate system and by acquiring the coordinate from an imported file. Usually while selecting the second option both project base point and the survey point will be moved to the centre of the Toposurface imported. The limitations and the usage of such points will be further explained in the next chapter while presenting the automatic script.

Last site manipulation included into Revit is the Graded Region. This option focuses on creating cuts and fills within the surface. Limitation linked while using such command is that the history of the changes will be not recorded.

Civil 3D

AutoCAD made its first appearance in the 1982. Developed by Autodesk it has been through around 24 versions where that make it as it is nowadays. For the purpose of the thesis, we should focus on the version number 13 in the 1996, that sees the

introduction of the expansion package AutoCAD Map 3D. This add-on finally integrates a series of product, such as Civil 3D ad Map Guide, that are GIS oriented. This software can localize the drawings, manage raster and eventually publish on the web. With the latest version it has been implemented the possibility of importing a building architectural shell into Civil 3D. According to the latest version of the software user manual, in chapter 42 it stated that with this new feature the site design team can:

- Finalize the site plans before the architectural design has been completed
- Obtain enough information to start preparing the site for construction
- Reduce the communication cycle between architectural and civil engineering teams

All these benefits are compliant to the idea of the BIM approach, the interoperability created will help to reduce costs and time during design, and if further changes will be necessary, also during construction.

To fulfil the exchange of data the building engineer (or the architect) that is following the BIM model should prepare a Design Package File (.adsk) that includes the gross area footprint of the building, with property and utility connection points. The data sharing with the site engineer is still at the early stages and this solution can't be seen as success for integrating such discipline into the BIM cycle but it is a good starting point.

The main actor that is involved in the usage of the software is the usually, as already mentioned, the civil engineer or the topographer and it is required a deep knowledge of the coordinate systems management and about the creation of maps of the sites. At this stage the engineer should prepare the model in a way that once is exported it will be charged with the useful information.

Dynamo

One of the most famous and old parametric software is for sure Grasshopper 3D for Rhino, this plugin made easy some modelling procedure that usually would have taken days. Thanks to a logical engine based on Python language it made Rhino being capable of executing scripts and automatize the creation of the model, speeding up the process of design. Along the line of the success of this software, starting from Revit 2017, the brand-new parametric modelling software Dynamo was added.

It opened many options to collect and process data automatically by setting logical scripts. Dynamo is currently using Python engine 3 and allows the community of the user to exchange script, nodes and workflows thanks to its open-knowledge forum.

This software is organized into a series of nodes, that include the script to perform, and a canvas where the nodes will be placed and connected. The mentioned nodes are equipped with input and output options that consists of the required data entry and the result of the process. The logic of computation is linear, so as common a coding script the software will read the first node and it will proceed along the connection by keep reading and executing what each element is describing. Below is shown a picture coming from the developed script that will be presented into the next chapter.
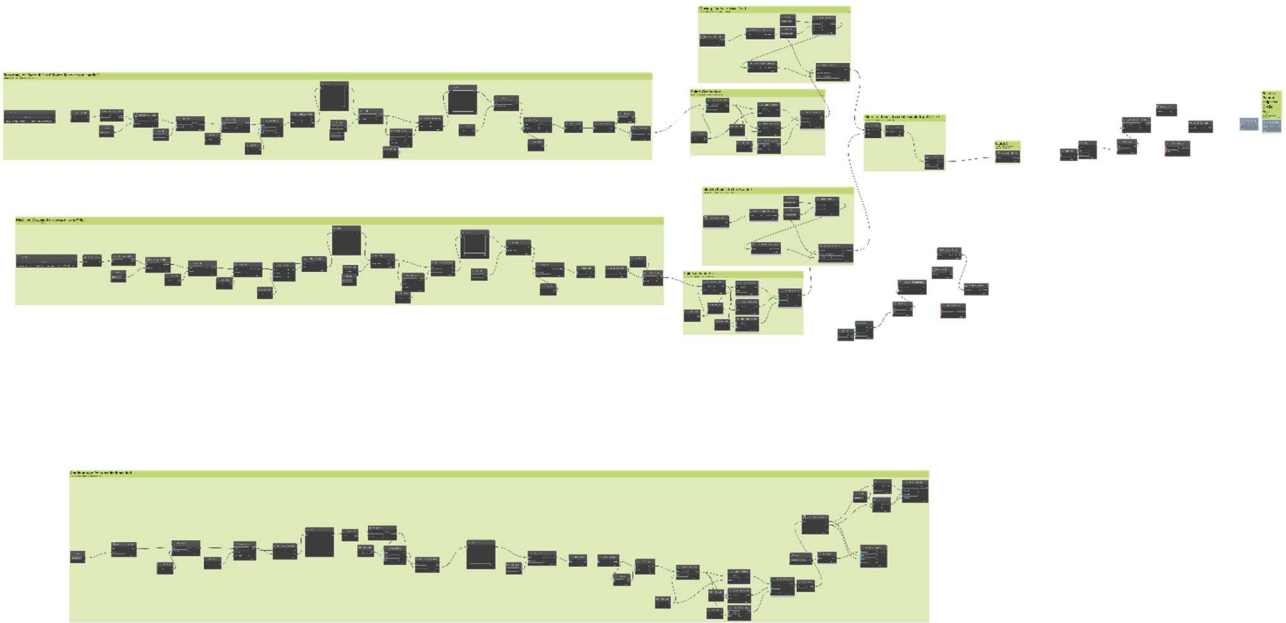
Figure 44 - Canvas overview, the nodes are represented as black boxes
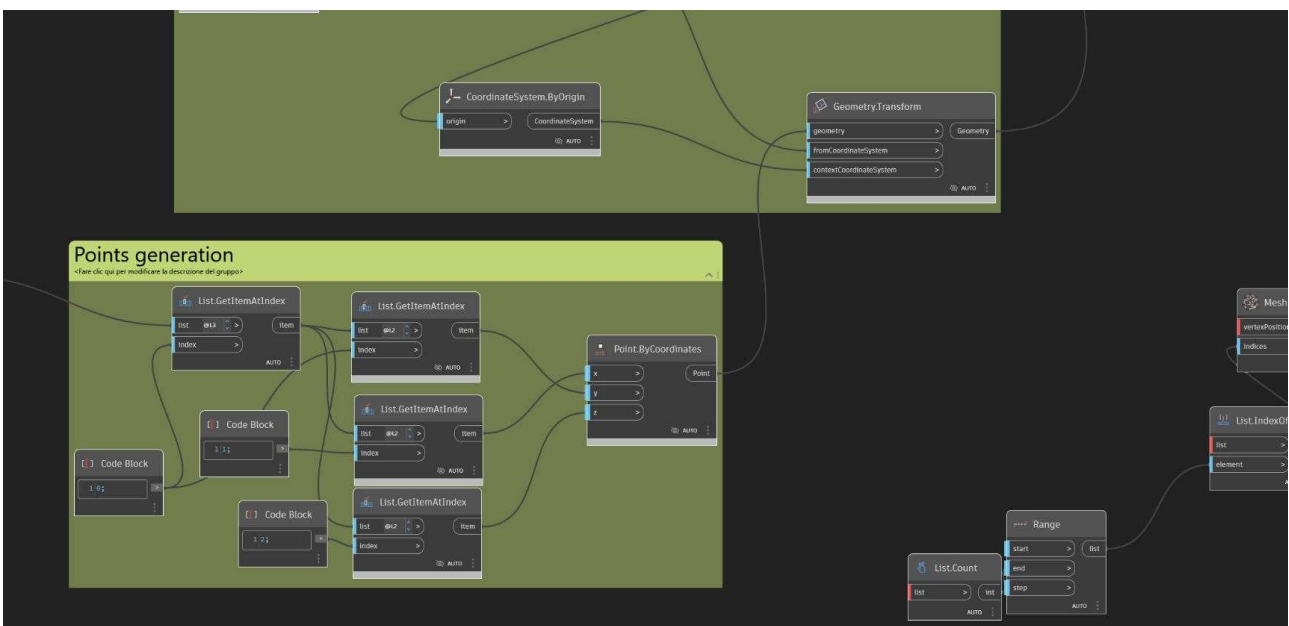
Figure 45 - Focus on part of the code, inputs, outputs and connections are visible

Within the latest version Dynamo is also included into Civil3D. The created scripts are based on the potentiality of the software in which is installed, the nodes that will be inserted to the canvas are so strictly linked to the command included into the software. So, Dynamo scripts that works into Revit environments may also work, with some translation, into the Civli3D platform. Such tool is often used by modellers to speed up repeated processes that usually are done manually, but we can't see this procedure as a definitive solution. The reasons are many:

- The script created may become outdated in time
- The created script is easily editable by anyone that has access to it
- The engine that performs the calculation is strictly linked to the computational power of the computer and may easily crash or idle for several minutes while executing the script
- It is required a high knowledge in programming and experience in logical tools

So, this tool can be cost effective if used by an expert to perform common operations, such as placing objects, update drawings and so on. But, for special applications or for study purposes, this software can assist the development of additional plug in or software based on the Autodesk suite. For the case study included within this thesis, Dynamo have been used for understanding the potential of both Revit and Civil and so provide study material and additional applications. As a quick introduction of the process that will be explained later it is reported below a quick anticipation of the next chapter.

"Geometry of the topography surface can be exported from Trimble CAD software using LandXML extension and via Dynamo script can be automatically modelled into Revit just by retrieving the points listed into the file, then all the geometry data regarding the excavation process can be moved from a triangulated (.ttm) file coming from the machine and processed inside Trimble CAD software to Revit to update the geometry of the topography surface. This method can be done for an undefined number of machines since is only referring to new points that needs to be added to the topography component. This allows the engineer to keep track of the working process visually and numerically (thanks to Revit Schedules)."

4.2.2 Machine side software

As was already explained mostly all the earthwork machinery can be equipped with the same technology, with the only differences of having different results. For example, we expect that a wheel loader will have higher variability in space while for the excavator we expect results that acts on the morphology of the site. Thanks to

the sharing of the equipment within the machinery we can analyse the outputs of the machines once almost for everything.

The machine guidance then will guide the different machine according to its main task: the wheel loader will be guided according to the material to be moved, the steam roller will be guided on the amount of pass and the quality of the compaction and so on.

The technology is now studied for the case of an excavator. The data relatives to the excavation depth, position and volume data are collected, for this case study, via Trimble Connected Community. This platform can already return a visual representation of the "as built" stage and can define what is the remaining volume to be removed to arrive to an as project situation.

The excavators are equipped with the GNSS antennas as already described and they are constantly mapping points, which are describing the position of the bucket blade using the following fixed mapping rules [32]:

- Mapping must be turned on, and a design or map loaded at least one mapping type enabled
- The system must be receiving high accuracy positions
- The machine must have moved at least 0.25 m since the last map update
- The machine must have moved less than 10 m since the last map update

The mapping types that can be subjected to automatic mapping control are:

- Pass count
- Terrain
- Radio
- Cut/fill

And the following conditions can be combined to control mapping:

- Minimum height – This condition is satisfied when the elevation of a cell on the current pass is less than the elevation of the same cell on any previous pass
- Bucket tip – This condition is satisfied according to the "Driving forward" or "always" condition.

Moreover, following this mapping conditions the operator can set a custom name for mapped points by giving it a name or ID that is then increased by an integer for the following mapped points. This can open the possibility to generate a series of data that makes the excavator a survey robot.

All these data are then sent to software and a LandXML file can be exported. The LandXML file has the same scheme as the one that is containing the initial survey and project condition. There are two ways of syntax in which can describe the topographical surface in two ways:

a) Break lines and 3D points
b) TIN surface with Points and faces

Being both files written in the extended markup language is possible to open them with a text editor and analyse their structure.

Furthermore, it will be explained the file coming from the application that deal with the productivity parameters linked to the machine.

4.3 BIM based time and space planning (Setting of the construction site)

As already introduced in the paragraph about safety, the document PSC also contains, as attachment, the time schedule and the planned site layout. The aim of the designer is to produce drawings about layout and diagrams about time/spaces for safety and productivity analysis. Usually, the excavation process takes place during the beginning of the construction phase where most of the temporary infrastructure are not still present in the site. But, especially for bigger construction site the heavy machineries may work also when other processes are ongoing.

Traditionally according to the site type, the number of spaces that may be required is consistently high. A brief list is given as follow [44]:

- Type and positioning of the fences
- Offices for the administrative figures
- Toilets and changing rooms areas
- Canteen (eventually equipped with kitchen)
- Walkable and drivable routes
- Material stocking areas
- Fixed working place (for onsite assembly and concrete works)
- Tower crane location
- Dangerous substances, gases, oils and chemical products stocking areas
- Electric cables and generators (safety measure included)
- Entrance and exits for trucks with wheel cleaning devices
- Parking place and disposal

While deciding the position of the areas the Layout designer should consider a series of relationship and rules that are linked to a specific element. Such relationships and rules could be defined by:

- Regulations and laws
- Standard of good practice
- Logical placement
- Client requirements
- Decision taken during the design

As an example, for this bullet point list, to follow the good practice approach while designing the internal viability of the site the designer usually considers the final internal routes trying to make them coincident, in this way there will be the soil preparation in advance the final realisation as designed. The access ramps need to comply to the correct minimum dimension, as law states, and to other dimensional requirements, such as compaction, material and slope in accordance with the climb abilities of the chosen machinery during design phase. The logical placement is referring to the logical relationships between the placed areas: the restrooms for the workers shouldn't be placed all within a spot if the site is too large, the administrative office shouldn't be placed too far from the parking lot and so on.

All these rules should be used for creation of a BIM database used by the software during the rule checking procedure. The rule checking procedure is a common practice for creation BIM database and modelling. It consists of a database that is filled with predefined rules and relationship that will be used to check the BIM model while design. The conversion of a traditional construction site to BIM based lead to improvements regarding the initial completeness and efficiency of the design and during the execution it can help the site managers in conducting quality control and analysis by collecting the spatial-temporal data of the operations. To complete such conversion, it may be required to produce 3D parametric model of the machinery, in order to carry the rules about their positioning, create additional plug in to be used for real time management and then to convert the processes and areas into IFC schema for the data exchange. All the components of the site require to be modelled in certain temporary positions that within the time it may change. In order to avoid the placement of two different entities we should refer to the IfcPlacement of the product with a period of validity, so a IFC time dependent extension is required. An example of 4D extension is given by Schwabe K. et al. [50].
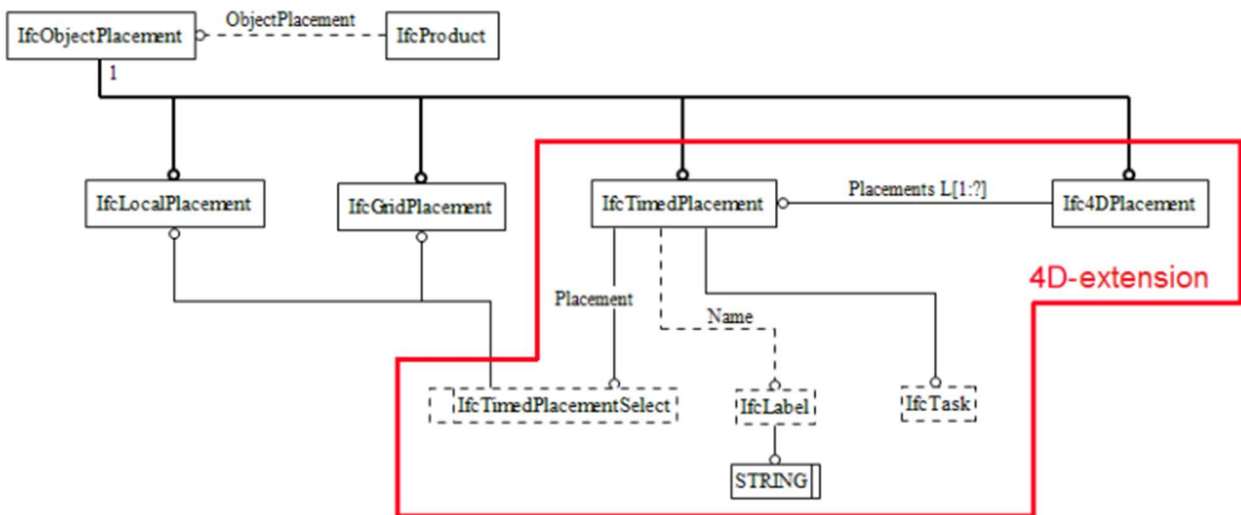
Figure 46 - Prototype of IFC 4D extension - [50]

Integrate the machine guidance system within the construction site allow to input data about the productivity in real time. The information may be then displayed: weekly, daily or hourly. The standard BIM software doesn't allow hourly o real time simulations but if correctly integrate with plug in they may be capable. Real time monitoring applications of the fleet and workers are already proposed by the industries, for example, Volvo proposes the Connected Map.

Figure 47 - Volvo Connected Map, www.volvoce.com

This application is able to connect all the machineries, workers and visitors within a single platform where are shared mutual locations, processes, areas and routes. This system is useful for a quarry that doesn't forecast the building of new structure, but to be implemented within the AEC industry it requires to be interoperable with the other disciplines, an example can be the introduction of additional markers or sensor that allow the entrance of additional process and environmental data inside the software. Now that is clear time and space are strictly connected within the construction site environment, we should mention the time organisation of the

processes. Each process is assigned of a specific code by the chosen classification system (e.g., UniClass) and it is inserted within a work breakdown structure, the coded process is then localized in time by means of GANTT chart. Such charts are very big and can be easily read if printed on paper but on the computer side it becomes more useful to be interpreted by a software.

To integrate the time and space within a BIM environment the useful entities are located at chapter 8.7 IfcGeometricConstraintResoruce,8.9 IfcGeometryResource, 8.5 IfcDateTimeResource, 5.4 IfcProdcutExtension (for space definition) and 5.3 IfcProcessExtension.

4.4 BIM-based quantity take-off

Among all the benefits of the BIM approach over a construction design, one of the most important is the quantity take-off. This application requires specific software and preparation of the model information and consequently a BIM expert. Quantity takes off (QTO) is not an end in itself but it precedes important tasks such as cost estimation, construction planning or tendering [27]. According to T. Farah [28] QTO is performed by quantity surveyors that manage the information that will be then linked to unit costs for labour, material and time of rent of machinery. Furthermore, project cost can provide indicator for productivity, feasibility analysis, financial requirements and approvals, budgeting, bidding and awards, warranty, maintenance and operation costs. Among all these usages once a QTO is performed can be even used as history of data about the performance of the specific group work, opening the possibility of a better forecast and simulation of future work.

QTO calculations are traditionally performed manually even when a 3D model is used, the main disadvantages of such process are [27]:

1- possible human errors due to manual labour
2- the measurement is sometimes up to human interpretation and if the surveyor has not the same vision of the project as the designer it may lead to different quantities.
3- The quantity surveyor may be less qualified than the engineer or the architects so he may have less sensitivity to eventual design or report errors.

These problems may lead to a wrong cost estimation with possible penalties as consequences.

So, an automated QTO using BIM can delete such problems, but it requires an accurate preparation. The lack of standard regulation for design measurement brings the designer and contractor to have their internal way of classifying and organize the

project elements having as a result a difference in language among the actors. BIM experts are required to have complete understanding and to forecast the input-output dynamics according to how the elements are modelled and parametrized [27]. The automatic routine of the BIM oriented software needs to be checked afterwards by an expert to assess the feasibility of the results, and if they represent the actual reality of the work performed. It is highlighted by A. Monteiro et al. [27] that during the construction (or excavation) process the level of detail of the information extracted need to be controlled in order to avoid an overflow of data that may lead to confusion or delays in calculations. As mentioned before a classification system is the base of the automatic process because it allows to have a good forecast of what the program will extract afterwards. This type of organisation for the processes is called a Work Breakdown Structure (WBS) and all the actors involved should use it. The available WBS classification are MasterFormat, OmniClass, Uniformat and Uniformat II, UniClass and CEEC [27]. A breakdown structure is generally described as a tree diagram with different levels and can cover different aspect of the construction work such as space, object, work, or project. A trend that is increasingly seen and nowadays consolidated is the use of IFC for classification, when an IFC object doesn't find a matching object in the proprietary data structure a manual IFC mapping is required [27]. Quantity take-off is then executed during the process of tendering or private offer for cost estimation and then is repeated periodically for updating the SAL, work diary and measures book. The concept of QTO relationship with the rest of the process can be seen in the diagram proposed by Monteiro A. [27].
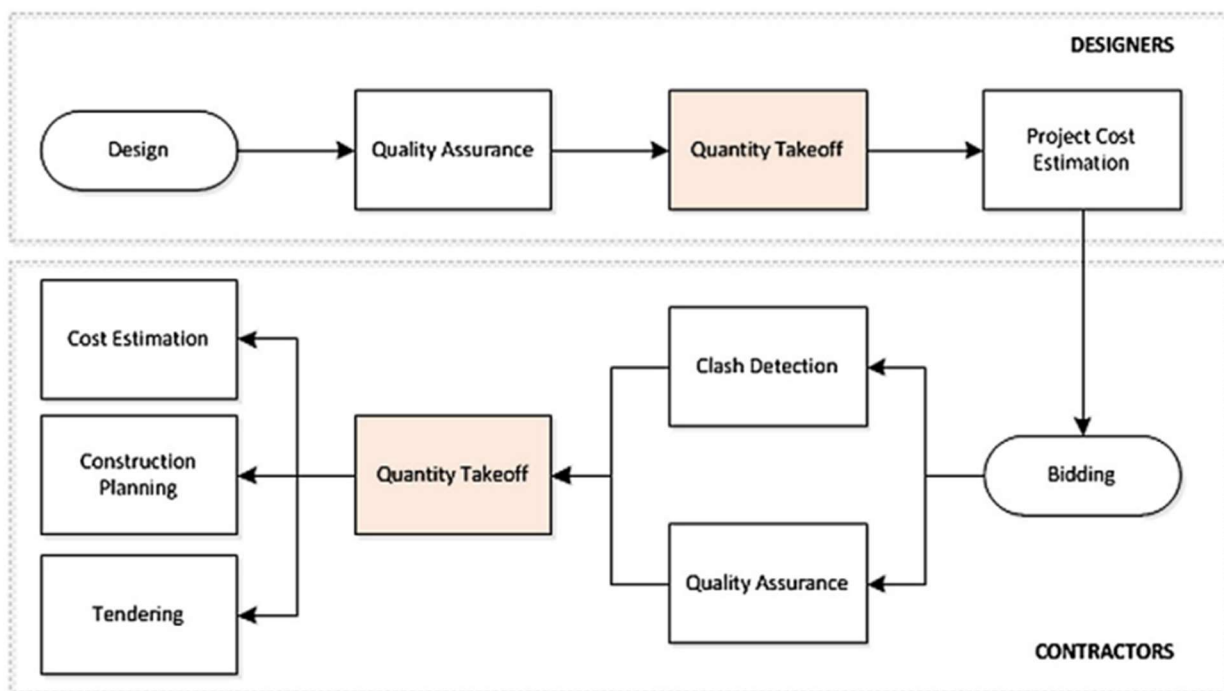
Figure 48 - Relation of quantity take off with the other major tasks in the project life-cycle - 47]

The lack of a standard about QTO creation and organisation is of course decreasing the speed of spread of such method. Within the case study and the proposed approach, it will be studied the results coming from the heavy equipment and how to use the automatic report for the monitoring of the costs linked to the earthwork machinery.

On the market there are many software that deals with the BIM quantity take off and the most know software house are Team System with the software CPM, Acca Software with PriMus and less known for the building field but more for quarries there is KontrolOn by Tecno and distributed by CGT. While the first two are BIM based and oriented to on the building environment the last is focused on volume and consumption calculations of the sites that performs high quantities of earth movement also with the aid industrial equipment.

4.4.1 Discussion above costs and prices

The quantity take off can be seen as the more detailed step before writing the bill of quantities used for tendering or construction process survey. It is performed by the software automatically, but it requires to execute a good preparation about the information that must be extracted. The parameters and properties that can be linked to a unit cost is dependent on the type of work performed and the type of material. Furthermore, the quantity take-off in the earth moving field can be used for other management purposes, such as management of the fleet, dimensioning of the tools chosen during design phase, management of stack pile and resultant materials, Etc.

The quantity takes-off considers all the resources about material and labour, where each of those has its specific unit of measure. In Italy we usually refer to the regional price list, which are produced to comply to what is said in the article "23 del D.lgs. 50/2016 e s.m.i. (codice dei contratti)", where all the materials and labour task are listed. More specifically, the earthworks processes are grouped within the volume 1.1 at section 1C.02. The purpose of this document is to provide official prices linked to the three main class of resources that are Labour, materials and equipment rent, with the final scope of providing an estimation of the design for tendering and management purposes. The prices listed can be overridden if supported by proper market investigation and/or agreement. Currently the price list is only up to human interpretations, in the sense that there is not an official digital version that can be read by the machine. However, some third-party software has already implemented the functionality to ease the process of research of the correct row. In fact, consulting the price list is a process that requires concentrations and time since the document is made by more than 500 hundred pages with, consequently, many prices items. As

mentioned in the article referenced as number [31], the municipality of Milan in 2018 was the first to introduce an initial draft of the attempt to make the price list becoming "BIM interpretable", the project sees the creation of a #TagBIM that wants to assign strings to each price item to be later linked to a specific element modelled into a BIM environment. The draft is available to the public at the official website of the Lombardy region, and it is an actual XML file including some examples of the possible future application. Biblus BIM website [31] mentions some specific benefits brought by the development of this new edition of the price list.

- XML is an open format that can be written with simple text editor and is also comprehensible by the humans and machines.
- Can be uploaded to any type of database
- Availability of the data thanks to the tags

The tables presented by the paper are composed by seven column and a large number of rows. Before getting into the analysis of the data that must be considered is shown as picture an example of type of work described by the mentioned document [30].

Comune di Milano - Prezzario Regionale delle opere pubbliche

01/01/2022

LISTINO

1C.02 - SCAVI - MOVIMENTI TERRE

CODICE	DESCRIZIONE	U.M.	PREZZO	% Inc. M.O.	% Inc. MAT	% Inc. NOLI
1C.02.150.0020	Scavo per sottomurazioni eseguito a mano a piccoli tratti, anche passante sotto le fondazioni o i muri esistenti, di materie di qualsiasi natura e consistenza, inclusi trovanti rocciosi o relitti di muratura fino a 0,750 m³. Comprese le opere provvisionali di segnalazione, protezione e sostegno del cavo e della muratura; il carico e trasporto delle macerie ad impianti di stoccaggio, di recupero o a discarica, esclusi oneri di smaltimento. Per scavi eseguiti:					
1C.02.150.0020.a	- all'esterno di edificio, fino a 0,80 m di profondità	m³	124,27	50,18 %	24,44 %	5,47 %

Figure 49 - Example of earthwork process described by the Lombardy Price List - [30]

Starting from the left we can observe the presence of a unique code linked to the process, this data must be reported, for legal and validation reasons, into the bill of quantities to reference the price choice to its source. The second column contains the full description of the work to perform, it can happen that some specific procedures are not expressed inside the list, so the designer should justify the price with a market survey. The column "U.M." is referring to the unit of measure that should be extracted with the BIM tool. At the fourth column we find the item "Prezzo" which is referring to the price of each unit, this parameter should be multiplied by the quantities extracted by the QTO at the offer stage. As last columns we find how the unit price is decomposed according to labour, material and equipment rent. These last columns can be used to precisely estimate the price and the incidence of each part.

It is important to clarify that the costs are perceivable only to the designer, while the client will see only the prices that also comprehend the remuneration of the actor

that gives the offer. As said, the price list should be utilized only for public tendering while for private contract the cost is known by the contractor thanks to previous study and estimations.

4.5 BIM and Machine guidance for safety

One of the possible applications of the machine guidance technology coupled with BIM is safety. During excavations or earth movements in general we may encounter existing structure beneath the surface or, in case of demolitions, the presence of dangerous materials that may harm the machine operator. Moreover, the construction site can be subjected to crowding, especially if we aim to overlap different process to enhance the productivity. Nowadays the construction industry is always under great pressure to deliver projects on time, efficiently and withing tight budgets but the safety area can't be neglected. The international Labour Organization (ILO), on its website, states that (2015) *"At least 108 thousand workers are killed on site every year, a figure which represent about 30 per cent of all occupational fatal injuries. Data from a number of industrialized countries show that construction workers are 3 to 4 times more likely than other workers to de from accident at work. In the developing world the risk associated with construction work may be 3 to 6 times greater. Many more workers suffer and die from occupational diseases arising from past exposure to dangerous substances".* In Italy, as reported by Rai News on its website, in 2021 according to the Inail (Istituto Nazionale Assicurazione contro gli Infortuni sul Lavoro), during the period between January and October it was registered a total of 1017 death, with a mean of 3 per day. In the face of such data, a particular attention to the safety of the operator is mandatory.

The capability of the BIM approach of managing documents and geometries opens a series of different ways of ensuring safety and from 2010 we can see an increment in number of publications.
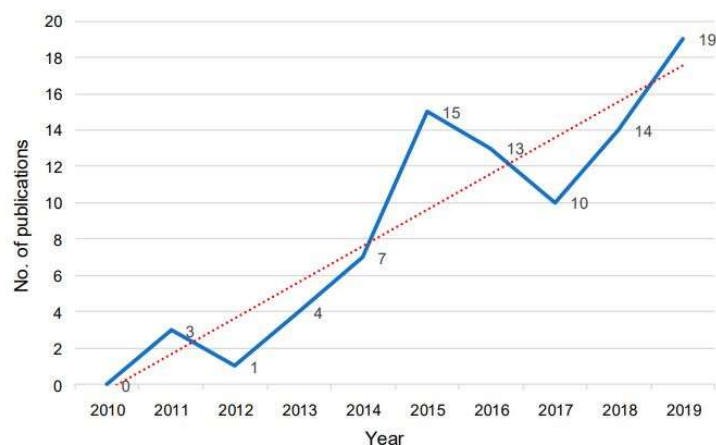
Figure 50 - Increment in BIM for safety publications - [35]

Taking advantage of the GIS potential, we can integrate, for example, the framework of piping or linear extended structure that lies underneath the surface to proceed with precision during the excavation avoiding reworks and errors in design.

In literature is possible to find many references to BIM used for safety management. Thanks to Fargoli M. et al. [35] we can summarize the main approaches used in eight macro categories:

1. Knowledge-based systems
2. Automatic rule checking
3. Scheduling information
4. Overlapping and clash detection
5. Proactive feedback
6. Training
7. Stakeholders' perception
8. Workers' behaviour

Each approach can give a contribute that adds to the others to create a complete and secure method.

For knowledge-based system we mean that the safety measures and limitations are taken according to some knowledge carriers such as regulations, documents, best practices and datasheets. This approach is strictly connected to the accident Prevention through Design (PtD), the documents quoted before are subjected to human interpretation that will then translate the information into actual constraint or design choices. PtD concept takes the characteristic from the theories of the hierarchy of controls and the Szymberski curve [37]. The hierarchy of controls ranks the possible measures that can be implemented to address safety issues at work sites, typical ranking of the possible decision that can be made after risk assessment are:

1. Elimination of the risk
2. Substitution of the "activity/object/product/machinery" with an equivalent and safer one.
3. Engineering controls to ensure safety even under risky activities (e.g., providing PPE)
4. Administrative controls
5. Personal protective equipment (PPE)

The first and higher three ranks require the designer intervention while the latter 2 do not rely on management for their effectiveness. On the other hand, the Szymberski Curve shows that is possible to influence the safety at the early phase rather than on

the later part, so at the design stage where the most relevant actor is the designer itself.
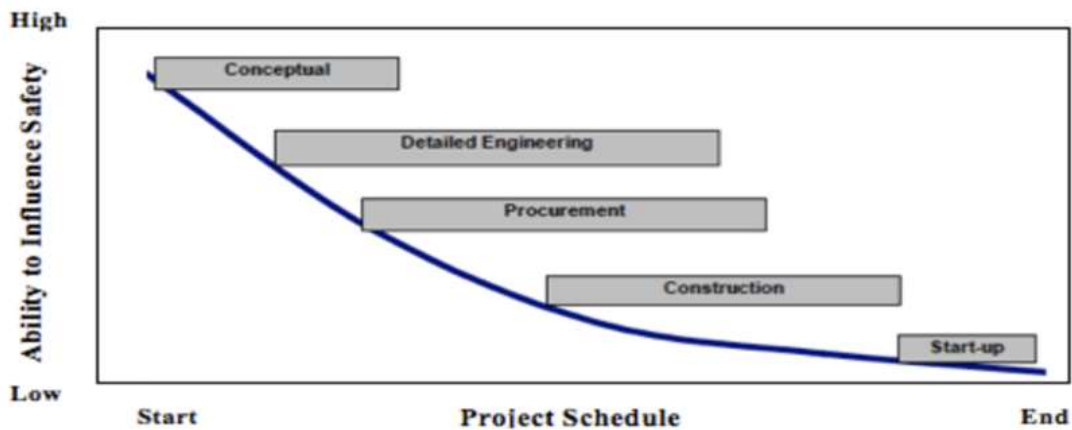
Figure 51 - The Szymberski curve - [38]

The automatic rule checking can be seen as a further upgraded application of what have been defined using the knowledge-based approach, it is possible to define some custom rules sets that can be driven by experience or by the specific site conditions. The scheduling information contained in the WBS are crucial in understanding the activities that will be performed, implementing the GIS information by georeferencing the activities by "geo Fences" is possible to further check physical overlapping or clashes.

So, as already described it is important to collect documents that carry the knowledge about safety. In Italy we can identify the D. Lgs. n° 81/2008 that highlight the most important aspect for risk assessment and at the article 100 is defined the mandatory presence of a Safety plan and coordination (PSC). This document is a technical report about the safety requirements linked to the complexity of the work with the aim of reducing or eliminating the risk for health safety of the worker. It also contains the estimation of costs related to the same topic, the time schedule, and it should be completed with drawings related to site layout and excavations.

Relevant content of the PSC is explicitly stated by the law, and it includes [40]:

- the description of the site such as surrounding and address, description of the building or manufact to be realised
- Description of the risks linked to the site area
- Description of the actors and their responsibilities
- report about risk assessment, linked to tools, machine and operations
- procedural choices and security measure about work, organisation and site layout

- Estimation of the duration of the site and phases described by the attached time schedule.
- Deep description and risk assessment about the overlap of works
- Estimation of the cost related to safety

4.5.1 Category of risks

During the development of a project that follows the BIM approach is common and good practice to categorize the data into groups. The model and the plugins that will interrogate it are useful if the process of data entry and organisation is done correctly.

With the help of the Italian Regulation and with the literature review, in particular the reference [45], it is possible to group the effect of certain risk under their magnitude of seriousness.

So, the risk will be considered as serious if the effect of its occurrence is putting in danger the life of the workers or the overall safety of the construction site

Risk Type	Risk Category
Machine Overturning	
Running over workers	
Impact with movable parts	Very severe
Electrocution due contact with electric cable	
improper usage of the machinery	

Risk Type	Risk Category
Burying or sinking	
Loss of material from above or material projection	
Contact or explosion with buried services	Severe
Slips and falls from height	
Risks due soil characteristics	

Risk Type	Risk Category
Vibrations within the cockpit	
Noise	
Bumps, Blows, Impacts, Crushing, compressions	Medium
Fire during refuelling	
Dust	
Abandonment of the vehicle	

Risk Type	Risk Category
Contact with mineral oils or derived	Low
Malfunctions	

The occurrence of these risks is strictly linked to the works that the machine is performing and to the other processes that are ongoing within the construction site area at the same time.

4.6 Volume calculation

Automatic volume calculation have been a matter of study in the latest studies. Haodong D. et al. [56] mounted a LiDAR and a web camera onto an excavator cabin to collect the exact amount of earth contained within a bucket by performing repetitive scans. A laser profilometer mounted on the stick is also tested by Ilpo Niskanen et al [57] that is capable of scanning the excavated pit. For sake of clarity the pictures extracted from the papers are reported below.

Figure 52 - Lidar on Cabin (left) [56] and Profilometer on stick (Rigth) [57]

These innovative ways of using small laser scan deserve for sure attention of the scientific community, but for the purpose of this thesis we would like to use what is already integrated within the machine which is the machine guidance.

To perform a quantity take off we should retrieve the volume of earth moved among all the other quantities.

There are many ways to hand calculate the volume some examples are: cross section method, prism method, grid method and horizontal section method etc. All of these are based on 2D drawings.

When using cross-section, we should firstly decide a certain density of parallel sections, which will give a more accurate result if chosen denser.

The volume is computed by multiplying the distance between cross sections by the average of the end cross sectional area, as shown below:

$$V = \left(\frac{A_1 + A_2}{2}\right) \cdot L$$
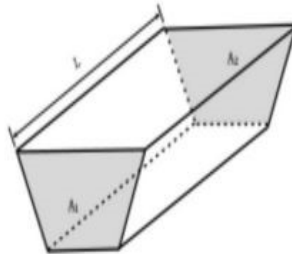
Figure 53-Cross Section Method

Where V is the earthwork volume between the cross section 1 and 2, L is the distance between the sections, A1 and A2 are the areas of the cross sections. This method is not convenient if we have an irregular excavation, and it takes time to do it so is not cost effective to monitor the as built condition frequently.

As we already introduce in the previous chapter, nowadays the positioning technologies have become more and more precise. Moreover, they are now implemented within the machinery, and we should search for opportunities to make the volume calculation more efficient.

The usage of 3D software allows to generate automatic volume calculation where the main requirement is to generate a reliable model. By using laser scans or UAV the as built surface can be generated by computer after the survey, that may be compared with the previous condition, this method is also called surface to surface method. To express the way of calculating it by using the studied software we can introduce the Civil3D volume dashboard. This tool can provide the deltas in elevation between two selected TIN surfaces by expressing the difference between cuts and fills. Thanks to the aid of Dynamo this function may be easily automatised by means of a simple script.
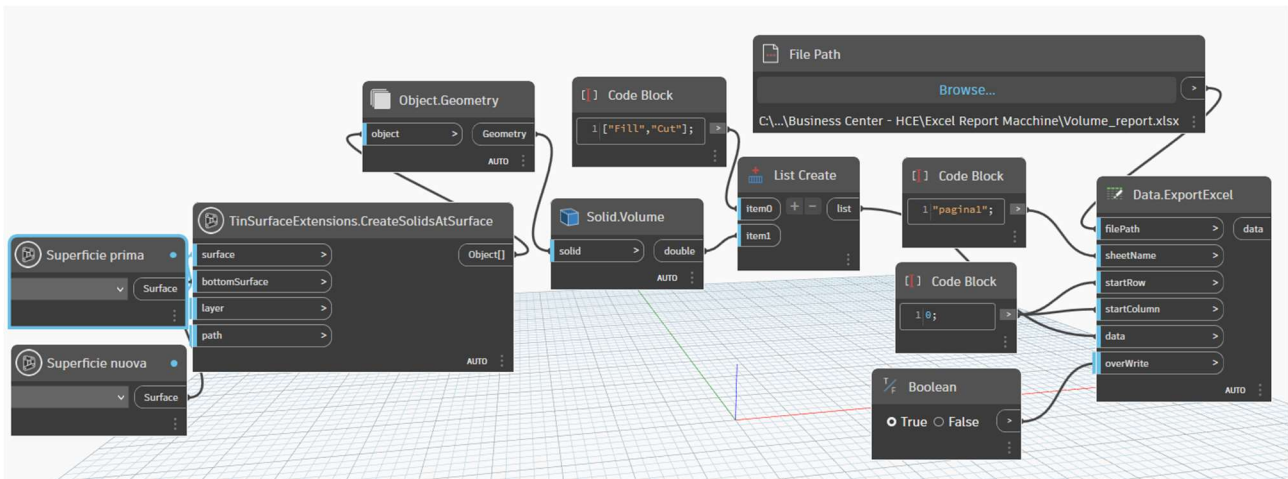
Figure 54 - Spreadsheet creation of cuts and fills

This algorithm requires the input of the two surface that must be compared by means of a drop-down list usable from the Dynamo player. Then by means of the node shown above the volume is evaluated and organised between fills and cuts within a single list. The list is then exported to the desired location, that can also be linked into the Dynamo Player, as an excel spreadsheet. The result can be then sent or organised in a more suitable way according to the project specification.

For Revit the calculation becomes more complicated. The software doesn't have any premade tools for toposurface volume calculations, and the solution proven by the community, among the Dynamo open knowledge forum, is to generate two toposurface with shared boundaries and perform a Boolean difference that is possible only thanks to the aid of Dynamo itself. The result then can be again exported as an excel spreadsheet similarly as done for Civil3D.

4.7 Excavation productivity

For the purpose of this thesis, it should be made clear which set of parameters and equations are used to determine the correct fleet sizing and choice during the design phase. Such calculations can be further implemented within additional plug in that helps the designer to perform quicker assessment of the machinery that will be deployed.

To plan an earthwork process we should study the main parameters and characteristics of the soil. The aim of these considerations is to provide a correct sizing of the excavator and the overall fleet, and they can be summarized as follows:

- The resistance of the soil to be excavated
- The weight of the material in bench or loose condition
- The granulometry
- Swelling of the material

- The contain of clay
- The humidity of the soil
- The abrasiveness

These results from the analysis are then included within the study of the productivity by means of coefficients and logical considerations. The productivity is also strongly influenced by the organisation of the site and by the working conditions such as road quality and weather.

Excavators

Excavators are versatile machinery that can perform precise cuts on the ground while being mostly stationary, their arms can be equipped with different tools to perform a wide range of operations, the main attachments are:

- Front bucket, for digging above the support plane
- Inverted bucket, for digging below the support plane
- Grab bucket for special applications such as wells
- Dragged bucket for dragging operations

The machine is composed by a 360° rotational turret and can moves thanks to tracks or wheels. The excavators are classified according to their weight and to the type of movement system [44].

Type	Weight (t)	Volume (m^3)	V (km/h)
Crawler	< 20	< 2	20-30
Wheeled	< 150	< 5	2 - 5

The main aspect that should be analysed is the time of cycle, for each machinery there are different set of repetitive operations that are characteristic of the type, for the excavator four operations can compose a full cycle:

1. Bucket loading
2. Rotation of the turret with load
3. Bucket unloading
4. Rotation with now load

Furthermore, it is common practice that the excavator operator will honk to the dumper driver to communicate the correct positioning of the truck or when the body of the truck is full.

The full cycle is usually named as T$_C$ and it is composed of the four steps listed before and it is used to calculate the hourly productivity of the machine. Usually, it is the

producer that gives the time of cycle in average optimal conditions that are, complete absence of obstacles, cut and loading from above, average operator ability and with angle of rotation of 60÷90° [44]. The average times of cycle according to the weight of a crawler excavator are shown in the table below.

Class of the excavator (t)	15	25	35	56
Average cycle time (s)	15	17	20	23

Furthermore, the excavation process has some ideal conditions of work that focus on angle of rotation, dimension of the dumpers, the ability of the operator, the type of soil and the content of rocks. The material that will be moved, out and in the construction site, has to be tested with specific laboratory tests, the most complete procedure is explained as follows [44]:

- Granulometry and Atterberg Limits, to perform soil classification
- Content of natural water and consistency
- Constipation AASHO Standard and/or modified according to CNR69/78 with the identification of the maximum density of the dry part (γ_{smax}) and the optimal humidity of constipation (wopt)
- Granulometric analysis before and after constipation, for materials that may contain instable or fragile aggregates
- Index of bearing CBR, for road infrastructure
- Site survey and vegetation vertical stratigraphy

According to the CNR-UNI 10006/63 the soil types are grouped into categories, from A1 (Gravels and sands) to A7 (Loam – Clayey) with the addition of the A8 (organic and marsh).

Figure 55 - CNR-UNI 10006, soil classification

Classificazione generale	Terre ghiaiose - argillose — Frazione passante allo staccio 0,075 UNI 2332 ≤ 35%							Terre limo - argillose — Frazione passante allo staccio 0,075 UNI 2332 > 35%					Torbe e terre organiche palustri
Gruppo	A 1		A 3	A 2				A 4	A 5	A 6	A 7		A 8
Sottogruppo	A 1-a	A 1-b	A 3	A 2-4	A 2-5	A 2-6	A 2-7	A 4	A 5	A 6	A 7-5	A 7-6	A 8
Analisi granulometrica — Frazione passante allo staccio													
2 UNI 2332 %	≤ 50												
0,4 UNI 2332 %	≤ 30	≤ 50	> 50										
0,075 UNI 2332 %	≤ 15	≤ 25	≤ 10	≤ 35	≤ 35	≤ 35	≤ 35	> 35	> 35	> 35	> 35	> 35	
Caratteristiche della frazione passante allo staccio 0,4 UNI 2332													
Limite liquido	—	—	—	≤ 40	> 40	≤ 40	> 40	≤ 40	> 40	≤ 40	> 40	> 40	
Indice di plasticità	—	≤ 6	N.P.	≤ 10	≤ 10	> 10	> 10	≤ 10	≤ 10	> 10	> 10 (IP≤LL-30)	> 10 (IP>LL-30)	
Indice di gruppo	0	0	0	0	0	≤ 4	≤ 4	≤ 8	≤ 12	≤ 16	≤ 20		
Tipi usuali dei materiali caratteristici costituenti il gruppo	Ghiaia o breccia, ghiaia o breccia sabbiosa, sabbia grossa, pomice, scorie vulcaniche, pozzolane		Sabbia fina	Chiaia e sabbia limosa o argillosa				Limi poco compressibili	Limi fortemente compressibili	Argille poco compressibili	Argille fortemente compressibili media plasticità	Argille fortemente compressibili forte- mente plastiche	Torbe di recente o rementa forma- zione, detriti organici di origine palustre
Qualità portanti quale terreno di sottofondo in assenza di gelo	Da eccellente a buono							Da mediocre a scadente					Da scartare come sottofondo
Azione del gelo sulle qualità portanti del terreno di sotto- fondo	Nessuna e lieve		Media					Molto elevata	Molto elevata	Media	Elevata	Media	
Ritiro o rigonfiamento	Nullo		Nullo o lieve					Lieve o medio	Elevato	Elevato	Elevato	Molto elev.	
Permeabilità	Elevata			Media o scarsa				Scarsa o nulla					
Identificazione dei terreni in sito	Facilmente individua- bili a vista		Aspri al tatto. Ingerenti allo stato asciutto	La maggior parte dei granuli sono individuabili ad occhio nudo. Aspri al tatto. Una tenacità media o elevata allo stato asciutto indica la presenza di argilla				Reagiscono alla prova di scuotimento*. Polverulenti o poco tenaci allo stato asciutto. Non facilmente mo- dellabili allo stato umido		Non reagiscono alla prova di scuoti- mento*. Tenaci allo stato asciutto. Facilmente modellabili in bastoncini sottili allo stato umido			Fibrosi di color bruno o nero. Facilmente indi- viduabili a vista

* Prova di cantiere che può servire a distinguere i limi dalle argille. Si esegue scuotendo nel palmo della mano un campione di terra bagnata e comprimendolo successivamente fra le dita. La terra reagisce alla prova se, dopo lo scuotimento, apparirà sulla superficie un velo lucido di acqua libera, che scomparirà comprimendo il campione fra le dita.

Furthermore, we identify to main type of soil, cohesive and non-cohesive. The first category are those materials that can bear to be cut with a vertical section and will maintain the stability for a limited period of time, while the second category usually follows the natural angle of repose induced by gravity.

So, we can identify some categories according to the combination of these factors, the higher the difficulty of execution the higher will be the real time spent for a full cycle. It is important to clarify that some aspect (e.g. the rock content) are not related to the design, so the natural problem related to the site should be taken into consideration and solved by means of correct equipment.

- **A.** Easy, not compacted soil with depth within the range of 0 – 40 % reachable by the arm. Angle of rotation not more than the 30% and unloading over a pile or truck placed in a lower plane
- **B.** medium difficulty, the terrain is compacted and has less than 25 % content of rock. The depth reached is within the range of the 50 % of the maximum reachable by the machinery and the angle of rotation is maximum 60°
- **C.** medium to difficult, the terrain is remarkably compacted, and the content of rocks is at 50 % the depth reach is maximum the 70% and the angle of rotation reach a maximum of 90°
- **D.** hard, the terrain is composed by compacted soil with content of rocks until the 70%, the reached depth is the e90% of the maximum reachable and the angle of rotation is up to 120°, furthermore the dumpers are small.
- **E.** very hard, the material excavated is mainly stone and the distance that is reached during excavations is about the 90% of the total reachable, the angle of rotation is more than 120°, people and obstacle are present within the area of work and the trucks are small.

This brief classification includes all the aspects that can influence the productivity of the excavator and in the next chapter will be furthermore applied. Of course, the conditions of work described in these five categories are not meant to happens in the exact same way but they just propose a list of conditions.

The hourly productivity of the excavator is calculated by means of the three following quantities, expressed in $\left[\frac{m^3}{h}\right]$:

- $P_{theoreica} = \frac{V \cdot r \cdot 3600}{S \cdot T_C}$
- $P_{Optimal} = P_{theoretica} \cdot f$
- $P_{real} = P_{Optimal} \cdot f \cdot \alpha \cdot B \cdot \gamma$

Where:

- V is the volume of material contained in the bucket
- r is the bucket filling coefficient
- f is the coefficient of performance of the construction site
- s is the swelling coefficient of the soil
- α is the coefficient of rotation of the turret if it is different than 90°
- β is a correction coefficient linked to the type of tool mounted.
- γ is the coefficient of depth of the pit
- T_c is the time spent to perform a full cycle

Is then report below tables taken from [44] with the values of such coefficients.

Values for α							
Rotational angle	45°	60°	75°	90°	120°	150°	180°
α	1.26	1.16	1.07	1.0	0.88	0.79	0.71

Values for s	
Crushed stone	1.5 ÷ 2.0
Gravel	1.0 ÷ 1.1
Clay	1.25 ÷ 1.4
Sand	1.0 ÷ 1.3
Soil	1.1 ÷ 1.3

Values for r	
Soil or clayey sand	100 ÷ 110 %
Sand or inert	95 ÷ 110 %
Hard clay	80 ÷ 90 %
Very fractured rock	60 ÷ 75 %
Slightly fracture rock	40 ÷ 60 %

Values for β	
Front bucket	1.0
Inverted bucket	0.8
Grab bucket	0.4
Drag bucket	0.75

In addition to these parameters, it should be assumed the amount of minute that machine will operate during an hour, a good compromise is to consider a total amount of work of 50 [min/h] which is the 83% of the total hour.

Existing earthworks optimization methods are classified into equipment fleet planning (EFP) and earth allocation planning (EAP) that identifies the most favourable equipment type, number and It calculates the anticipated earthwork productivity according to the most efficient time and place positioning of the machinery within the working schedule. To ensure the optimal cut/fill operations it is required a deeper study Han-Seong Gwak et al. [60] elaborated a computational method to assess the most cost-effective sequence of excavation activities based on the quality (or hardness) of the soil excavated and the time and space location of the pits to be dug. Such, innovative and interesting way of planning the earthworks operation should be taken as best practice for future works.

Dumpers

To complete the design of the excavation part of the fleet, we should consider the dumpers or the position and dimension of the stocking piles. In fact, if the system addressed to the stocking of the material is not proportional to the productivity of the excavators, we may have increased waiting times either on the excavator side or the trucks side. To fulfil this task, it is required to have a clear understanding of the soil characteristic by knowing the volume occupied by the loose condition of the material, while for the management point of view of the stack piles, the route and positions of the trucks it will be treated in the paragraph referred to the space and time setting of the construction site.

The trucks are mainly subdivided in two main categories:

- Dumpers, used for moving the material within the site
- Trucks for public road usage.

The first type are medium to big size machinery equipped with a rigid or tiltable box that allows the material to be stored, its structure can be either rigid or articulated and its movement functions are carried by the combustion engine combined with the hydraulic turbine, similarly to the other earthwork machinery. Its dimension and main parameters can be summarized in the following table.

Carry weight (t)	Full loaded weight (t)	Volume (Plane filled) m³	Speed (km/h)	Drivable slope* (%)	L (m)	l (m)	h (m)
5	8.5	3	25	45	4.8	2.1	2.05
10	19	6	50	45	5.8	2.5	2.8
15	26	9	65	35	7.3	2.5	3
20	35	10	52	33	7.2	2.9	3.1
35	62	19	57	30	8.05	3.7	3.5
50	88	25	56	30	9.4	4.35	4.15

* With good condition of the road

Where the dimensions reported are following the scheme presented below.
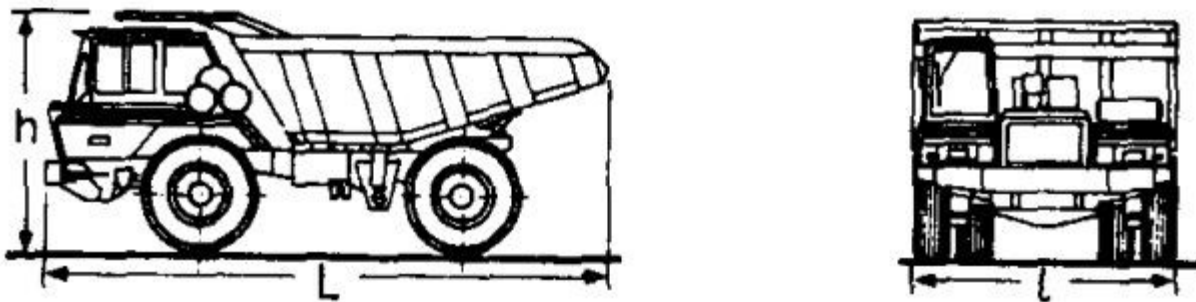
Figure 56 - Dimensions of a dumper - [44]

The second type are trucks that are allowed to circulate along the public roads. In Italy, to be considered compliant they should follow the D.L. vol n. 285 del 1992 and the D.P.R. n. 495 del 1992 and their following integration and modifications [44]. These trucks are composed by a trailer and a cabin that includes the driver and the combustion engine and are furthermore classified according to the number of axes of the wheels and if they have an integrated tipper body or not. The dimensions of these trucks can go from 12 m to 18 m with a weight that ranges from 18 t to 44 t. According to the available power generated by the engine these trucks can climb slopes with 20% ÷ 30 % maximum and these aspects are all to be considered later in the organization of the internal roads.

For a correct and efficient sizing, the number of passes that the excavator should do in order to fill the body of the transport vehicle are between 5 to 8 otherwise the truck can be considered either too small or too big. This aspect can be so checked on site according to the idle time that the truck or the excavator have. In addition to these it should be considered the travel time from the loading place to the unloading

one, so for a getting a chain type of work it should be studied the travel time and the number of trucks.

Of course, during the excavation process other machinery are involved while performing the overall activities and the parameters that are usually linked to all of the vehicles are: the time of cycle, the hourly productivity and in special case are included some quality parameters.

5 Case study

The scope of this chapter is to propose a task flow for integrate BIM into earthworks process. The following procedures are the result of what have been discussed until now. So known limits and potentialities of the problem we can make the consideration included in the following paragraphs.

Furthermore, it has been given the possibility to study the actual machinery technology through the result taken from a real professional case, so it will be discussed the results obtained. In addition to what has been said, it has been also possible to follow a calibration on site of an excavator, more specifically a CAT 330 equipped with Dual GNSS RTK system connected to a VRS.The organisation of the current chapter is done by providing:

- Paragraph 5.1: description of the experience of calibrating an excavator on site
- Paragraph 5.2 Discussion and analysis of the outputs of software and machine
- Paragraph 5.3 The creation of a script for merging the as built mapped surface with the surface model of the actual condition of the site and the consequent discussion of the results
- 5.4 Discussion of the possible application and approach for managing the outputs of the machine within a BIM environment for the control of a construction site
- 5.5 Discussion of the possible application and approach for quantity take off using a BIM oriented automatic calculation

5.1 Machine Calibration

In a real design and management scenario of an earthwork process the machine calibration is performed only at the beginning of the executive phase, sometimes is even done outside of the site area. It will be presented here as the first paragraph to explain the process that can ensure the data that we will use and discuss later.

To ensure that the mapped point coming from the machinery are reliable and precise to the order of the millimetre we had to calibrate and georeferenced the equipment. This process is meant to be done only once because, unless technical problems, the machine will be then calibrated and connected to the Satellites (or VRS) and constantly even with the engine off, the position will be saved and stored until next usage.

This activity requires a total station and four targets, of course also one physical target can be enough since it needs to be aimed one at a time.

Figure 57 Total station and Targets

Firstly, we levelled the TS and saved its position with GPS coordinates. Then, we moved ensure that the receiving paddles where correctly working even with the excavator placed on an inclined surface. Lastly, we placed the excavator with the stick, boom and bucket at their maximum horizontality. From this step and on both the machine and the station will be not moved again to avoid losing the references. The aim of this process is to map specific point points of the machine to being inserted in the tablet on board, with the purpose of telling the software which are the actual dimension of the machinery.

Figure 58 Correct Positioning of the Boom, stick and bucket

Then we inserted the targets at hinge of the bucket, the first hinge of the boom at the body level and two at the GNSS paddle receiver.

Figure 59 Target positioning (GNSS receiver, boom and bucket hinges)

At this stage we aimed with the total station to each target, their position is saved as a list inside the tool and manually we report on a paper the result. These positions will be then inserted inside the software of the excavator with the actual distance of the targets from the external surface to the centre of the boom and bucket respectively, and for the one position on the paddles we measured the vertical offset of the aimed point. Lastly, we gave the machine also the dimension of its track and its overall dimension of the body.

Figure 60 Point list on TS (left) and Target position offset on bucket hinge (right)

At this point the heavy machinery knows its dimension in the space and the position received at the paddle level is now converted trough calculation as position of the bucket blade, furthermore the excavator now knows with a certain margin its

dimension and has the possibility to figure out if it is going to crash over some obstacles or similar.

5.2 Software and output discussion

As explained in the previous chapter the machinery, if equipped with machine guidance and sensors, will output precious information. It will be shown and explained the result from the case study.

For the spreadsheet handler Excel is widely known. Its popularity made him the first choice for data management. But this software can lead to severe errors if the codes, tables and data are not well protected or set. This may happen because the software is not able to recognize logic errors or accidental changes. For this reason, its contribute should be kept to the bare minimum, or the passages of calculation that will performed should be reduced and manually controlled for sake of security.

5.2.1 Topographical surface as points and break lines

The exporting method a) is the most branched, we firstly show in the picture below the core of its definition.

```
    <Metric linearUnit="meter" widthUnit="meter" heightUnit="meter" diameterUnit="meter" areaUnit="squareMeter" volumeUnit="cubicMeter"
  </Units>
  <Application name="Business Center - HCE" manufacturer="Trimble" version="29.0.6817.37908" timeStamp="2022-05-10T11:47:09">
    <Author createdBy="loren" timeStamp="2022-05-10T11:47:09" />
  </Application>
  <Surfaces>
    <Surface name="superf">
      <SourceData>
        <Breaklines>
          <Breakline brkType="standard">
            <PntList3D>6045756.9100000 608848.9300000 158.0090027 6045757.2500000 608849.6100000 158.0339966</PntList3D>
          </Breakline>
          <Breakline brkType="standard">
            <PntList3D>6045757.2500000 608849.6100000 158.0339966 6045756.9100000 608849.6100000 157.9980011</PntList3D>
          </Breakline>
```

Figure 61 – Example of Breaklines exporting Type, LandXML file

it defines the modelled surface using the terminology Breakline identified by a name, that in the case of the picture is "standard". Each line is then described by two points included in the branch "PntList3D" that are defined using UTM coordinates where the first number is the UTM northing while the second is UTM easting. The third value is the orthometric altitude. This way of expressing the topographical surface is complicated because for each line is opened and closed a section where the two points inside the list are hard to be retrieved by means of simple scripts and logical computations so it is potentially heavy to be read by the PC. Furthermore the 6 geometric values linked to them are only separated by a space and are on the same command line. Lastly, this export method differentiates the "Standard" break lines that compose the inner surface of the site with the "Boundaries" drawn in the model. This feature represents the main advantageous point because it exports the external boundaries that usually are used for volume calculation in or grading of the surface inside Revit environment.

5.2.2 Topographical surface as TIN surface

Exporting as triangle faces and vertex, is basically a way of decomposing the polygons into simpler elements. Before describing again is shown below the screenshots taken by a sample.

```
<Units>
    <Metric linearUnit="meter" widthUnit="meter" heightUnit="meter" diameterUnit="meter" areaUnit="squareMeter" volumeUnit="cubicMeter"
</Units>
<Application name="Business Center - HCE" manufacturer="Trimble" version="29.0.6817.37908" timeStamp="2022-05-10T11:48:49">
    <Author createdBy="loren" timeStamp="2022-05-10T11:48:49" />
</Application>
<Surfaces>
    <Surface name="superf">
        <Definition surfType="TIN" elevMax="163.1479950" elevMin="147.7290039">
            <Pnts>
                <P id="1">6045754.1900000 608842.1300000 159.6979980</P>
                <P id="2">6045713.3900000 608855.3900000 158.1009979</P>
                <P id="3">6045726.9900000 608855.3900000 156.3430023</P>
                <P id="4">6045740.5900000 608855.3900000 156.4420013</P>
                <P id="5">6045754.1900000 608855.3900000 156.3480072</P>
```

```
</Pnts>
<Faces>
    <F>6217 2951 3991</F>
    <F>690 1 7339</F>
    <F>6240 5338 5339</F>
    <F>739 4469 296</F>
    <F>6851 875 5683</F>
    <F>1509 2666 4577</F>
    <F>5424 3872 2408</F>
```

Figure 62 - Sample of syntax within a LandXML TIN file

This method is generating a list of points under the element "Pnts" that are listed thanks to a unique id predefined by the exporting software. Each point is defined inside a single line that opens and close with the element called "P". The coordinates UTS described by northing, easting and its orthometric height are then collected separately in each line. This feature is the key point of this method, and it becomes very useful while reading it on dynamo. It is possible to take the full list "Pnts" and collect many elements as the points with their coordinates. Anyway, with the actual computational power it's possible that the computations of retrieving the coordinates of each point can be difficult for large files. The element "F" according to the LandXML website is "a surface face. It contains a space delimited list of "id" references for 3 (TIN) OR 4 (grid) surface "P" points" [9] so this means that the 3 values (in case of TIN) are the indices of the points composing the face.

5.2.3 Productivity data files

As shown previously in figure 13 an excel file (or .csv) can be exported from the machinery. These files are mainly referring to "Material Summary" and "Cycle data". It is then remembered that this kind of report can be plotted by any machinery type (wheel loader, excavators, dozer and so on) of any brand, as long as they are equipped with the proper sensors and processing devices.

The following tables are prepared to collect and present what the current technology can provide to the engineers that deal with the machines. Such data are the core information that must be included within the BIM database of the PIM The parameters collected are so listed in the tables below, where it will be assigned a code for internal referencing purposes

Material Summary				
ID	Parameter Name	Data Type	Description	Application
M01	Bucket payload Measurement	Date and Time	Time of the material weight recording	Localize the data in time
M02	Bucket payload sequence	Integer	Value describing the current count of buckets over a specific destination	Analysis of productivity and efficiency
M03	Bucket Payload (t)	Float	Weighted material in bucket	Productivity studies and checks
M04	Truck Store time/Date	Date and Time	Time of registration of the last fill of the truck (or pile)	Bill management and costs
M05	Truck total buckets	Integer	Number of buckets assigned to the truck (or pile)	Efficiency study
M06	Truck Payload (t)	Float	Total ton stored in a pile or truck	Bill and quantity
M07	Operator Description	String	Name assigned to the operator	Personnel check
M08	Material ID	Integer	Material moved (user defined)	QTO study
M09	Material description	String	Material description for human interpretation	/
M10	Truck ID	Integer	ID assigned to the truck (or pile)	For QTO and bill/Cost management
M11	Truck Description	String	Truck description for human interpretation	/
M12	Custom lists (1-4)	Any	4 columns for possible custom parameters	/

M13	Print ticket number	Integer	Not allowed in Italy	/

This report is mainly about the quantity of earth moved and is strongly controlled by the machine operator. He must select the material that is being moved and the destination of the material (pile or truck) from the tablet inside the cabin. The most important datum is the payloads records (M03, M06) because fundamental for remuneration of the contractors and for checks for volume of earth moved compared to the as built surveys. In a BIM environment the Parameter M10 can be linked to a specific report creation for identification of the destination of the material moved inside the trucks. For destination is meant, clients in case of buyers or dumping site for wastes. This file allows a very detail management of the material moved and can be considered reliable if the machine operator remains precise within the selection of material and trucks. This report works better for wheel loader that takes material from piles while for excavations is not always possible for the operator to be accurate while declaring the material moved, so it is referred to the material as a collective name.

Cycle Data				
ID	Parameter Name	Data Type	Description	Application
C01	Start Time	Date and Time	Time of initiation of the task	Localize the data in time
C02	Operator	String	Name assigned to the operator	Personnel check
C03	Cycle Name	String	Description of the activity	Efficiency study
C04	Total Cycle Time	Integer	Total cycle elapsed time	Efficiency study
C05	Cycle fuel (l)	Float	Fuel consumed during cycle	Cost analysis
C06	Moved Payload (t)	Float	Ton moved within cycle	Additional detail for productivity study
C07	Start latitude	float	Initial Position	GIS Link
C08	Start Longitude	Float	Initial Position	GIS Link
C09	Destination Latitude	Float	Final Position	GIS Link
C10	Destination Longitude	Float	Final Position	GIS Link
C11	Machine empty and stopped Time (s)	Integer	Idle time	Efficiency study
C12	Machine empty and stopped Distance (km)	Integer	/	/
C13	Drive – Time (s)	Integer	Elapsed time during movement	/

C14	Drive – Distance (km)	Integer	Distance covered	/
C15	Various – Time (s)	Integer	Elapsed time during activity called "various"	/
C16	Various – Distance (km)	Integer	Distance covered during activity called "various"	/
C17	Custom lists (1-4)	Any	4 columns for possible custom parameters	User defined additional lists
C18	Print ticket number	Integer	Not allowed in Italy	/

The report about cycle adds some more information, but the acquiring of the data is done by the on-board AI. The recognition of the work performed is done thanks to algorithms that consider the geographical position of the machine and the engine speed. It is possible to perform such calculations because in general the earthwork machineries are powered by a diesel combustion engine that also power the hydraulic system, so if the machinery is working stationary but it requires high hydraulic power for the movement of the arms it will revs the combustion engine to increase the pressure within the pistons. We can so identify the most important and reliable datum, the cycle fuel (C05). It is easy to detect, so its value can be considered reliable, and it can consequently be used to monitor the costs. The recognition of idling also can be considered as reliable because the revs of the engine are constant and minimum and its positions is not changing, idle condition can be used to assess the proper sizing of the fleet. In an efficient scenario the idle times should be reduced to the minimum. Each line of the excel file that has been exported is then linked to the geographical position having so the possibility of georeferencing the data in space.

The georeferentiation can be used in a BIM environment by including the area in which we expect certain activities, for example a dumping area for the haulers. Nowadays the applications already allow the user to create "Geofences" that are basically predesigned areas that helps the AI in recognise the activities.

These two files are clearly not built for a BIM environment since their syntax is not precise and organized. It is clearly visible from the data related to the operator, in the two file the parameter C02 and M07 are both referring to the name or description of the operator, but they are placed in a different column number and with a different description. This poor organisation of the file itself create the need of adding a step of data harvesting and organization before inputting it.

5.3 Automatic merge of the as built and the existing surface
5.3.1 Description of the case study

The case study refers to a quarry located in the northern area of Italy. The extracted result taken are the mapped points that the excavator registered during its regular routine. The excavator, a CAT 330, is equipped with a machine guidance system operating with GNSS and RTK via VRS, so without a total station on site. The designed surface used to guide the operator is inserted by the topographer (or the engineer that is following the excavation) remotely from his office and the machine operator had only to select it and stat excavating. The entire procedure was performed as normal routine according to the state of the art and no BIM approach was applied, so the purpose of the project was only to execute an excavation for material extraction with no BIM based automatic control on costs, volume checks or other management issues. The aim of the study is to analyse what is currently on the hands of the professional and understand what can be done to increase the efficiency and, in case of a building construction site, how to integrate the information transferred among the site and the office with the other actor acting on the construction procedure.

To schematize the procedure to obtain the design surface and then proceed with the excavation the following diagram is proposed. The study performed is focusing from the step number 6 since it was an excavation already in progress.
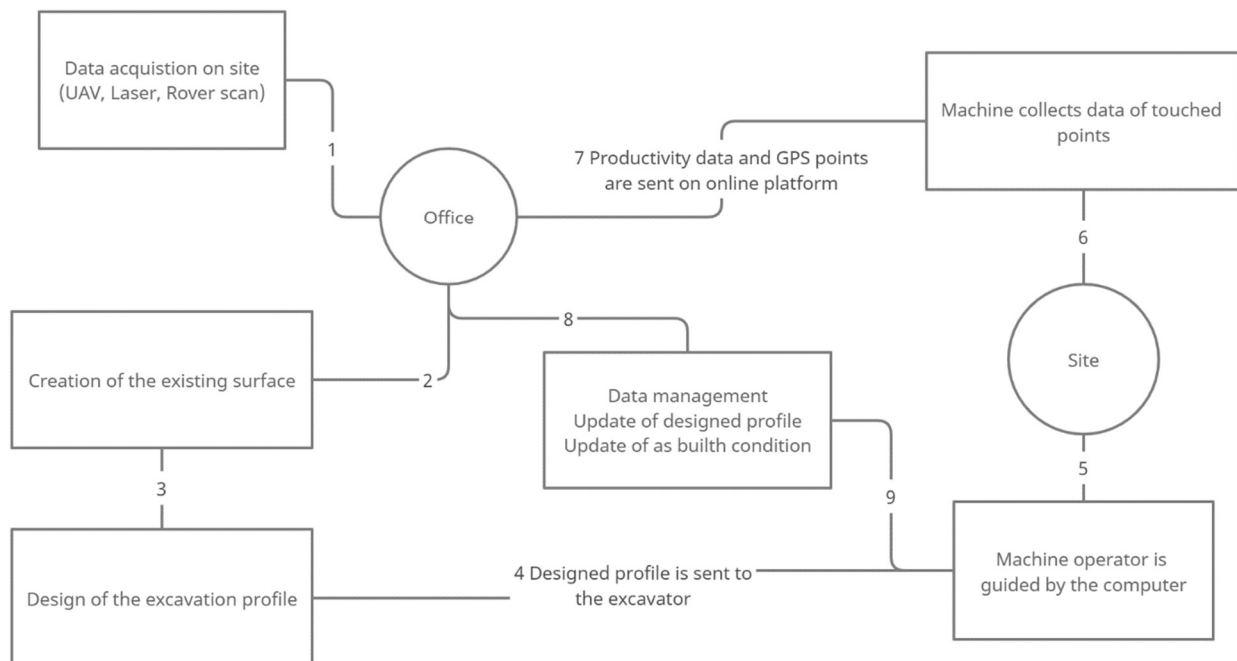
Figure 63 - Machine Guidance workflow

The correct workflow should start from the acquisition of the current shape of the site, in this way it will be more convenient and precise the update of the as built condition using the modelling software. For this case study and, unluckily, for many projects this step is usually skipped, resulting in the complete neglection from the software about the overall initial state. The operator, to be properly guided needs only the design profile of the excavation since the excavator can constantly know the elevation, latitude and longitude thanks to the positioning devices so step 1 and 2 are commonly, in part, but this may create further problems if we want to have a complete modelling of the current state, to later compare with the as built condition. What is done during surveys (Step 1) is only taking the key point of the site for future calibrations. During step 4 the complete, or part, designed profile is sent to the machine where the operator can select it and work. Then the cycle of the management of the productivity data and mapped points is performed trough the steps 6, 7 and 8.

Step number 6 is automatically done by the machine according to the mapping setting chosen and step number 7 is the automatic data flow from the machinery to the browser application visible from the office. Process number 8 and of course number 9 is the one dealing with the modification of the surface or treatment of the data that can be then consequently sent back to the machine for project updates.

The software involved are:

Step	Task	Software	File Extension
1	Survey and calibration o the site	Specific tool software	.cal
2	Management of survey data, creation of topographical surface	Autodesk Civil 3D or Trimble TCB (or HCE)	.dwg
3	Conversion of the designed profile for machine guidance software	Trimble TCB (or HCE)	.ttm .cal
4,5,6	Project is visible from the office and on the machine tablet	Android application (machine) and browser application (office)	/
7	Data are automatically transferred to the browser application	Browser application	.tag .LandXML .dwg .ttm .cal
8,9	Sending back to the machine the updated model if needed	Software from step 2 ad 3	/

The data that are accessible from the office are useful for the engineer that is following the excavation process in terms of updating of the topographical surface, volume extraction, type and amount of machinery involved within the site and cost management thanks to the productivity files that have been explained in the paragraph before. Unluckily, the files studied regarding the mapped surface and the productivity are referring to two different sites, so the data included are not comparable but is anyway possible to analyse the potential information available.

It is shown in the picture below, the scheme proposed by Trimble to explain the involved data exchange and platforms during the usage of the machine guidance system.
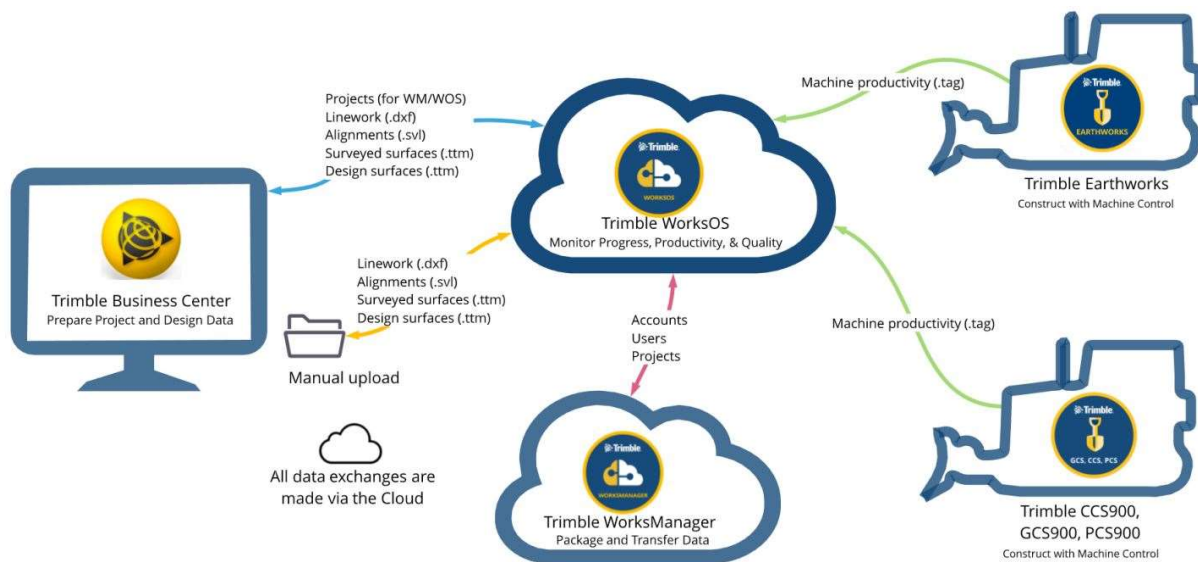
Figure 64 - Platform and data exchange involved - [47]

The process starts with the acquisition of a. ttm surface from the browser application Trimble WorkOS that is readable only through the software Trimble Business Centre (TBC). The .ttm is then linked within the software with its file .cal (calibration file) that have been produced during the initial survey. This link allows the .ttm file to be correctly and automatically georeferenced. TBC is a 3D CAD based software and it is possible to use for surface management and modifications, but in our case it has been used to produce a .LandXML file that express the TIN surface as a series of boundaries and vertices (see paragraph regarding software outputs). The .ttm exported is including only the mapped point of the desired time span that have been previously selected during export. The mapped surface is then inserted into dynamo thanks to a "file link" node and trough the designed script the mapped points are merged within the existing surface. If the mapped file contains reliable and precise data, therefore the .ttm is a surface describing the actual excavated area, we can have an automatic model update of for example the Revit model. Such update of the model can lead to different advantages, such as clash detection of activities during construction or update of schedules and quantities. Furthermore, a graphical representation of the as built condition can be further helpful for BIM based drawings and for visual check of the client.

5.3.2 Preparing the automatic script

Dynamo can translate routine operations into automatic scripts, so it is necessary to study and develop an algorithm that follows the logic of the manual procedure. The attempt that have been made is for understanding the added potentiality of data management given by Dynamo.

The idea is to simulate the scenario of having the surveyed existing surface modelled within the main software, that can be either Revit or Civil 3D, and to add the mapped data collected during the executive phase. The result came from 3 weeks of study and two version of the script. The initial one is used to test the possibility of automatise the modelling procedure of a topographical surface via LandXML and the result is briefly shown in the picture below.
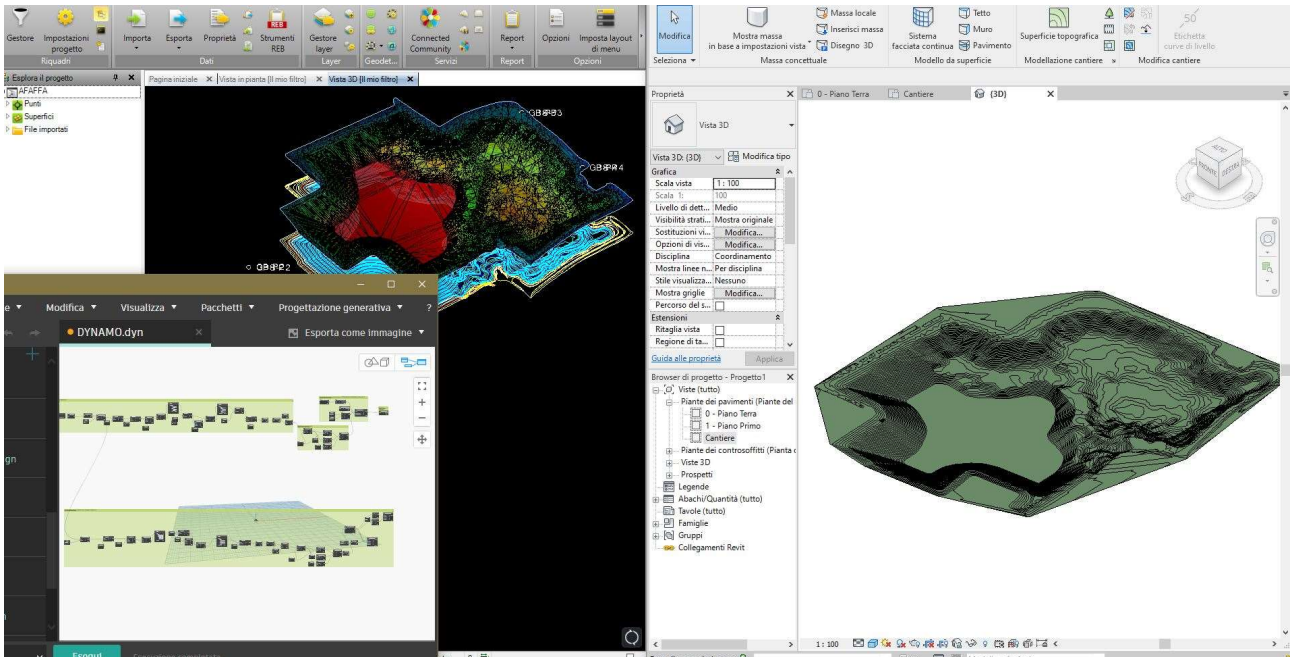
Figure 65 - Overview of Dynamo script (lower left) HCE software (upper left) and the result into Revit (right)

This test shown that Dynamo can read the file exported from the civil engineering software and is able to create the instance of a toposurface without any loss of precision. The second version will then include the mapped surface generated by the machine and it will merge it with the as built surface.

Below is presented an overview of the second and last version of the script in order to list the logical parts in which it is divided. The nodes used are included within the vanilla version of dynamo and into the Lunchbox package.

Among the knowledge shared within the Dynamo forum and the Revit/Dynamo guide there are no examples of similar application, so the script is designed to experience the potential of the calculator.
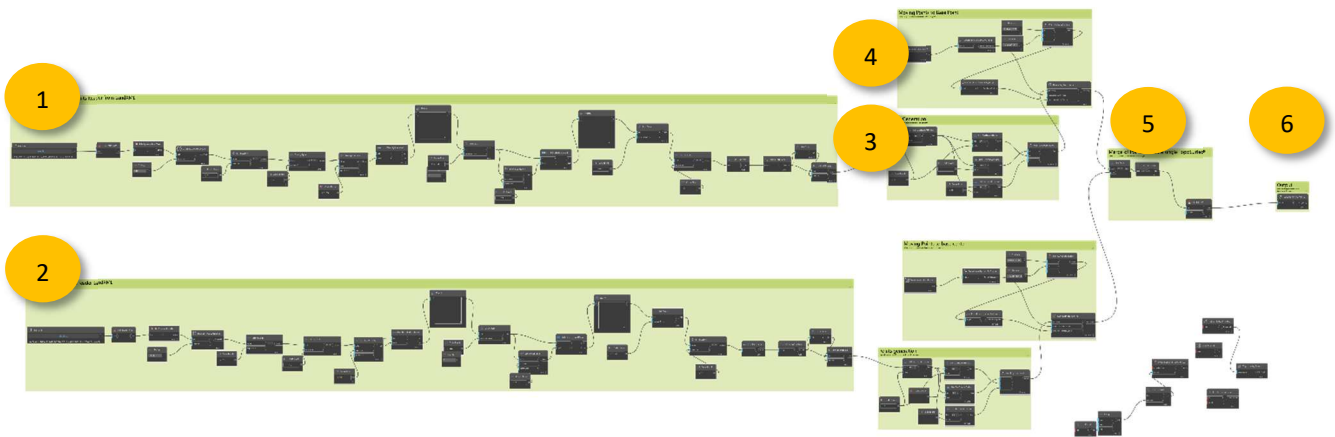
Figure 66 - Overview of the script for toposurface update

Since the canvas of Dynamo is too large and the number of logical steps are consistent, it will present each group with further focus on its sub parts.

Group 1
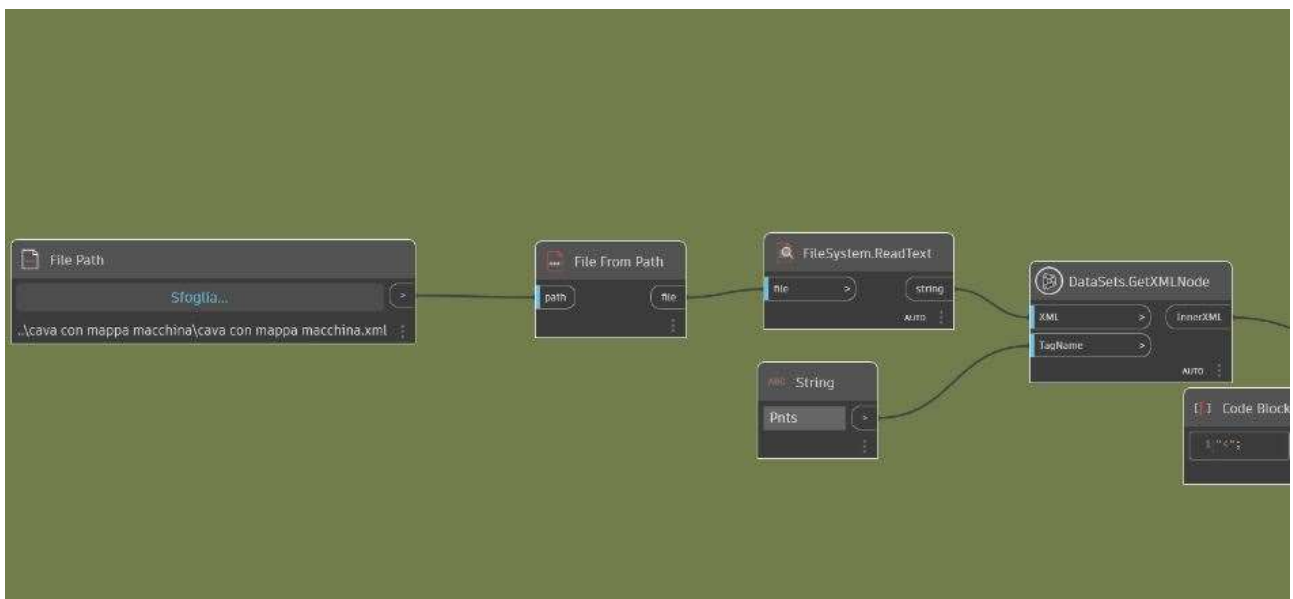
Figure 67 - Data entry

The group 1 is addressed to read the TIN surface .(LandXML) file regarding the initial condition of the site and extract the coordinates of the vertices.

At the very beginning it is specified the File path of the .LandXML and it is asked to read the text inside of it. Then as we already explained while speaking about the data organisation of the file, we can get the node called "Pnts". In this way we enter the section where all the points are listed, the result is a list of one single element that includes the coordinates of all the thousands of vertices that compose the TIN surface.
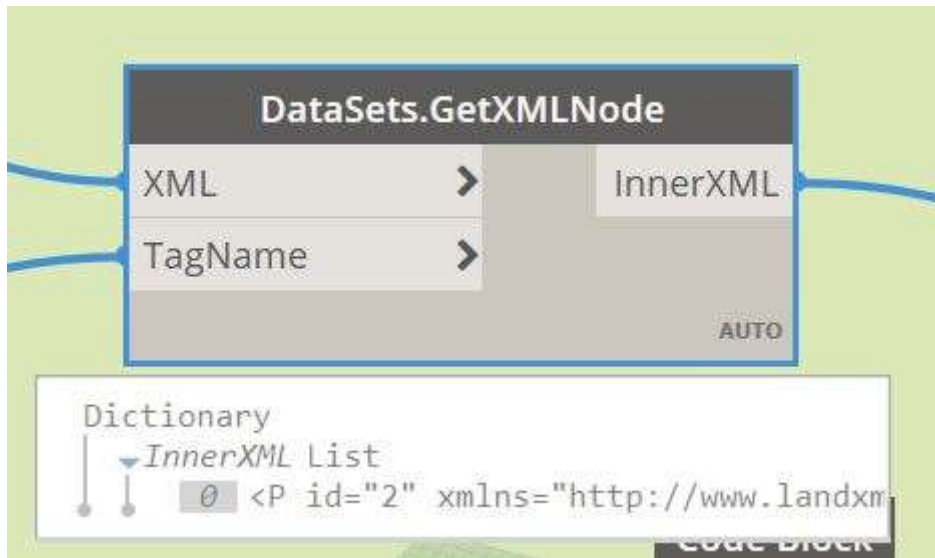
Figure 68 - Result of reading the "Pnts" node (using a lunchbox node)

So to divide a string we can identify the recurrent symbols that are used to split the topic. Within the programming language it is common to use <, >, spaces, commas and other symbols, in this way the data are readable from the computer.
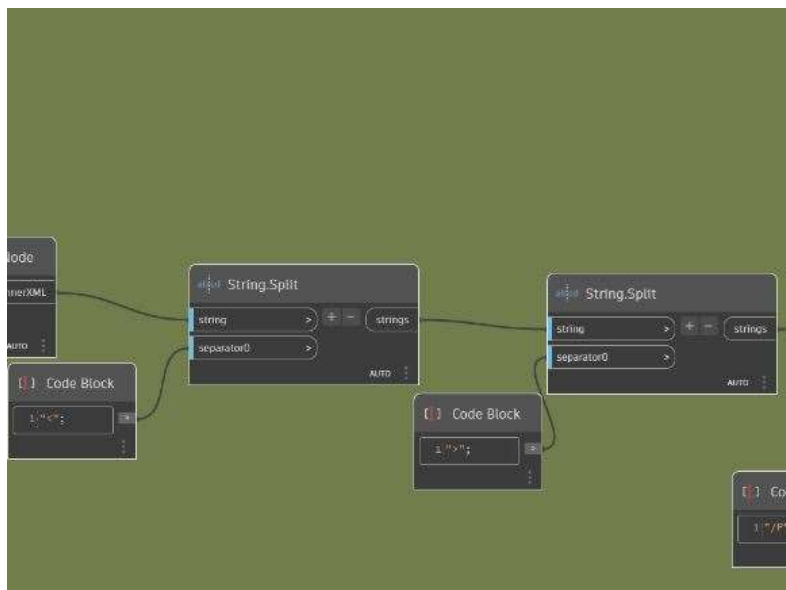
Figure 69 - String split

So it is used a couple of code block that are useful to specify what is the discriminant used for separating the initial string into multiple elements within a list. The result can be seen in the picture below.
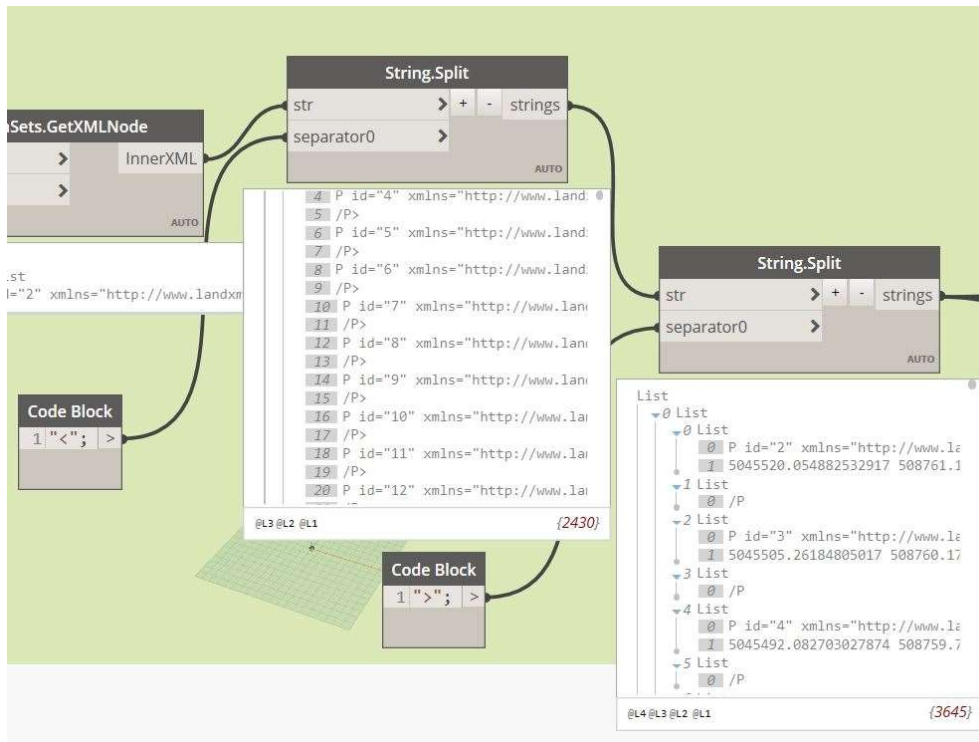
Figure 70 - String splitting result

After splitting twice, we can already observe that we get a nested list where the inner one contains elements that are purely the longitude, latitude and altitude of a certain point but still written in a single string and nested until the level 4.
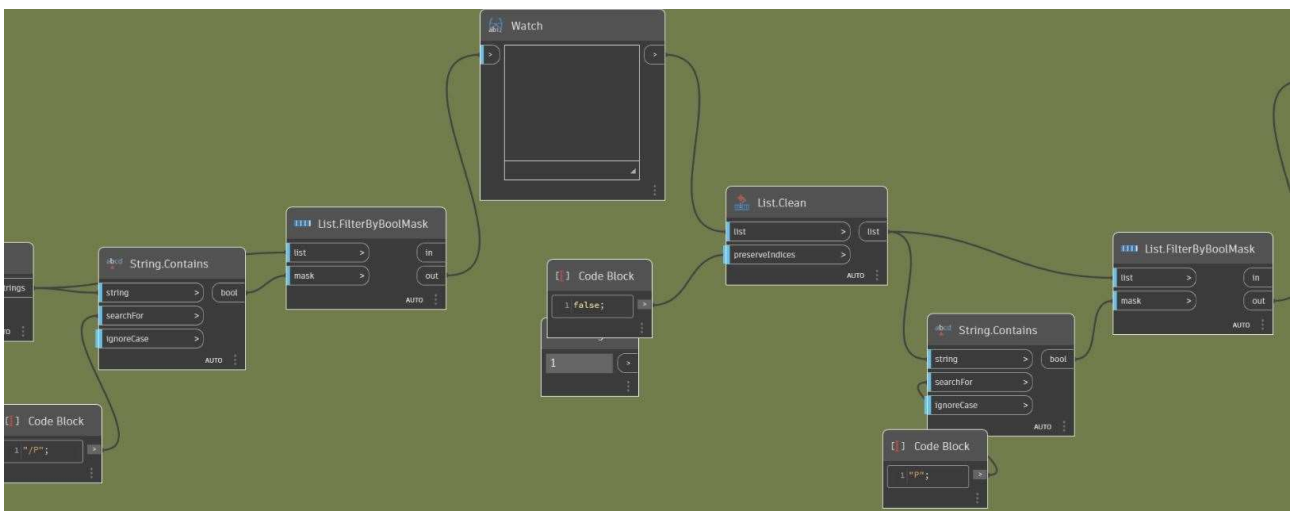
Figure 71 – Cleaning the list

So it is necessary to delete all the useless element that are contained within the sub lists. It is used a combination of the node "String Contains" that acts like research of key element and "List filter By BoolMask" that creates a Boolean mask of true and false of the elements that are triggered by the "String Contain". It is visible the result thanks to the two picture below, that are consecutives within the code.

Figure 72 - Boolean Clean list by /P (above) and P (below)

Now we are getting closer to the final result, we have still a nested list where each element contains a string that carry the information about the point coordinates. At
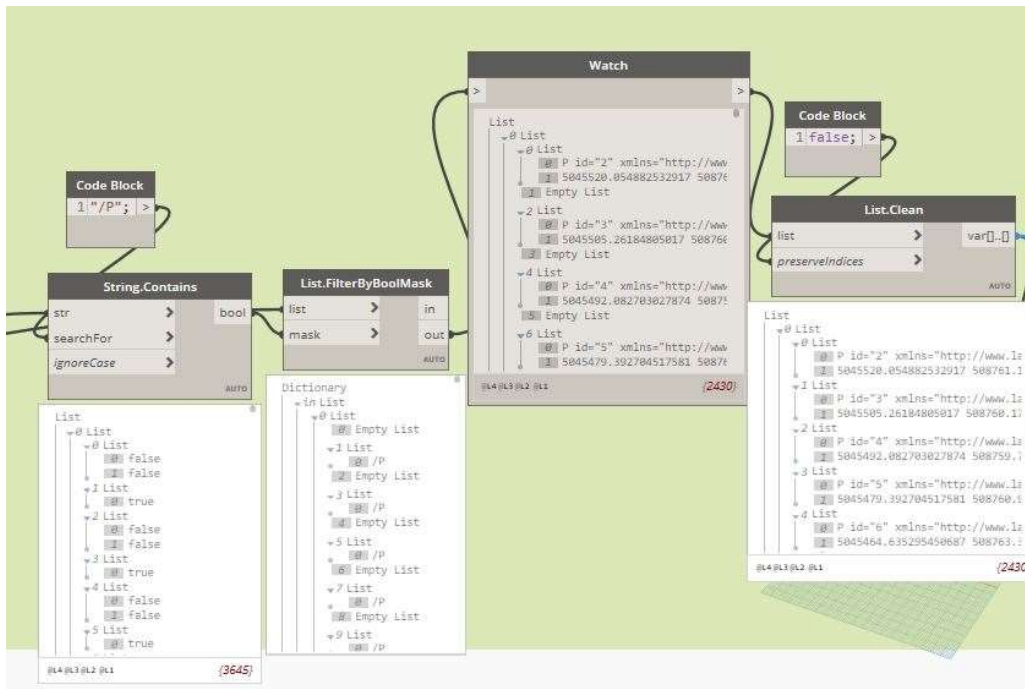
this level Revit or Civil 3D are not able to extract the data as geometric point because they are generic strings.
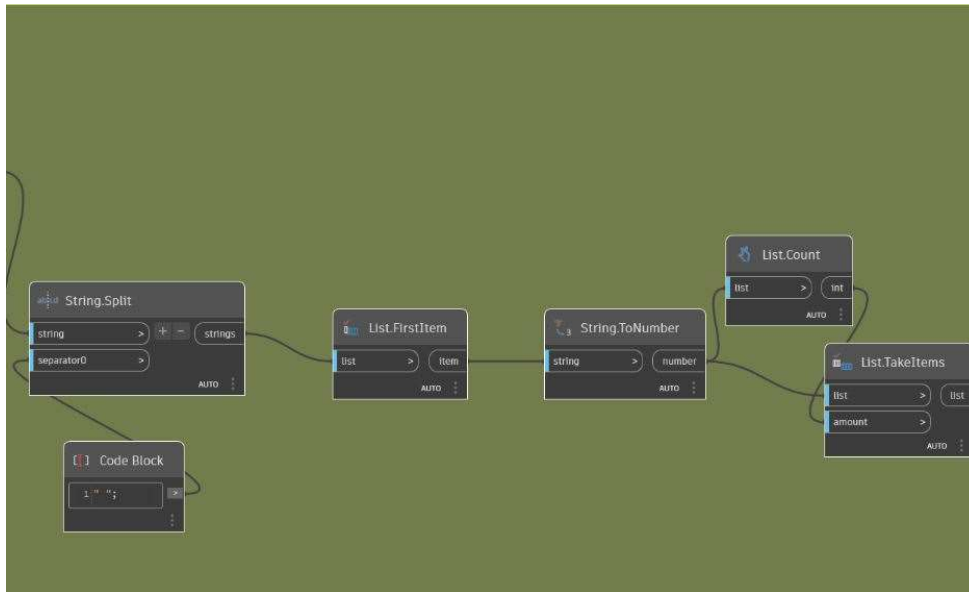
Figure 73 - Finalizing data

We can so now divide the strings according to the character " " that means "empty space", so the elements are now split within their own list into 3 strings that are referring to the coordinates of that specific point. Then it is taken the first item of the nested list which is the list of points and it is counted the number of it. The latter is then used to extract from the nested list all the sub lists and covert the strings into numbers. In this way we have a Level 3 list containing numbers that carry the desired information. It is again shown the result into the next picture, where it is clearly visible that before "String.Split" the points were still not retrievable.
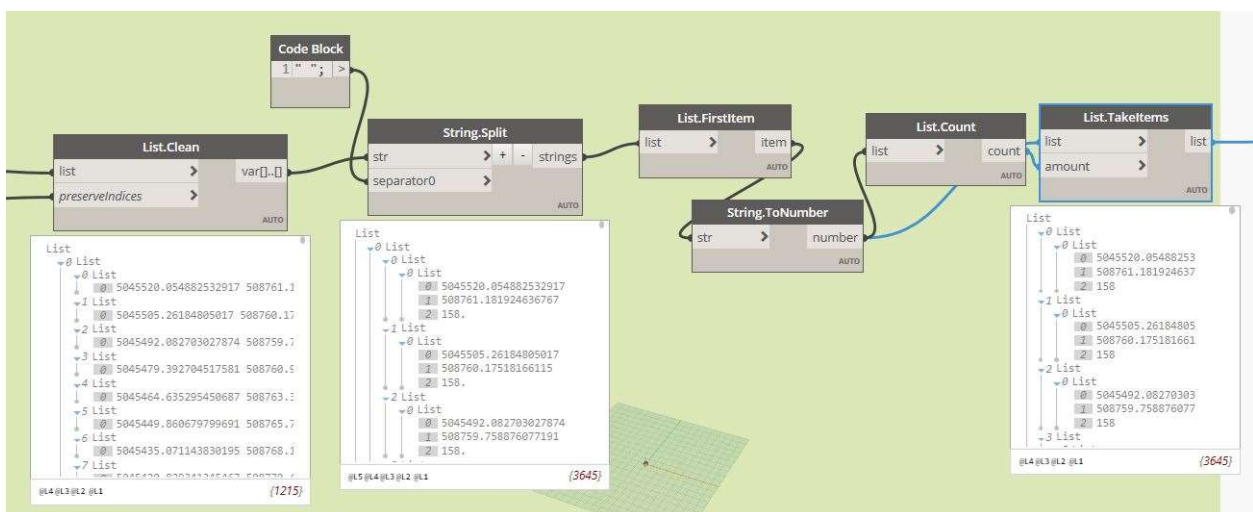
Figure 74 - Data retrieval

GROUP 2

This group of nodes is the exact copy of the group number 1, but it is loading the LandXML file of the mapped points coming from the machine. This is possible because the logical scheme of the data organisation remains unvaried.

As comparison of the amount of data processed, we can summarize them within a table.

File	Number of vertices	Dynamo number of elements	File size (KB)
Original Surface	31221	93663	4263
First map (May 10)	7463	22389	939
Second Map (May 26)	36125	108375	4871

We can see that Dynamo will have to handle a bigger number of elements, this is due the fact that each point is split within its coordinates in fact if we divide the number of elements by three, we get the exact number of vertices contained within the file. It is then reported that within the LandXML file extracted by the machine the ID of the points come up to 7681 for the first map and 36338 for the second, but the number of entities is less, so it is suggested that within the numbering of the points there are some discontinuities within the sequential numeration. The process has been controlled multiple times with the aid of the Note Pad Numeration of the lines and with an Excel spreadsheet and it is proved that the script didn't lose any data. This problem in point numeration of the machine software could be taken in exam in future study.

Group 3
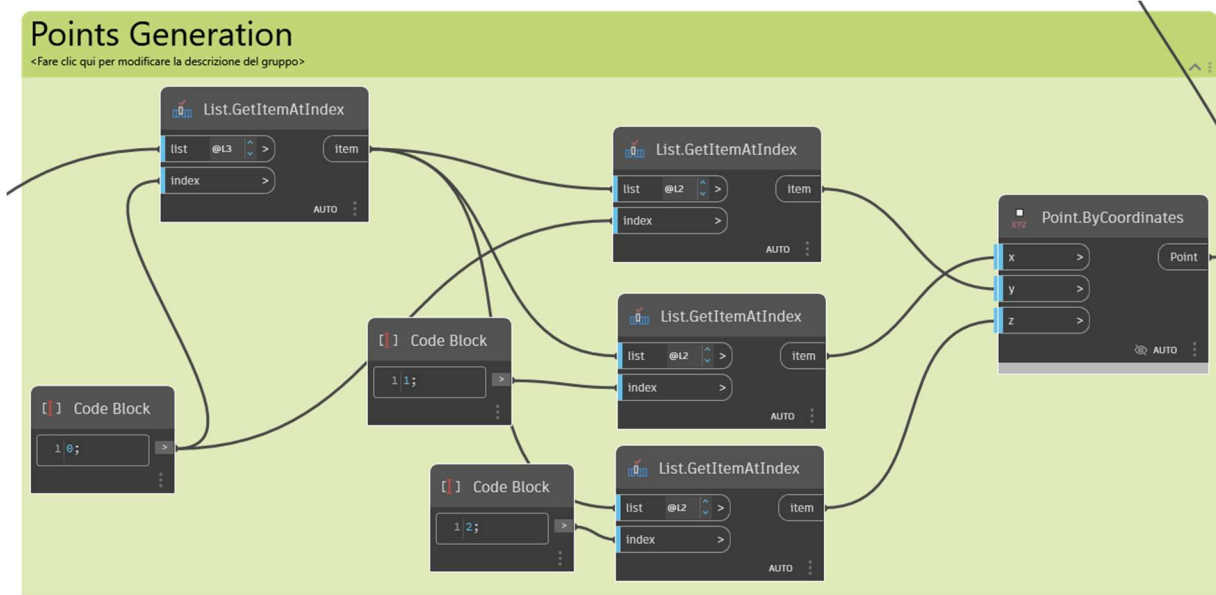
Figure 75 - Group 3, generation of cartesian points

To translate the numbers into cartesian coordinates the items contained into the list that are grouped under the index 0 are taken under the level 3 of nest. Then in each sub list the items with index 0 1 2 that represent the longitude, latitude and altitude are assigned to the node that generates cartesian points by coordinates. This procedure is done both for the current condition of the site and the entry data coming from the machine.

Group 4
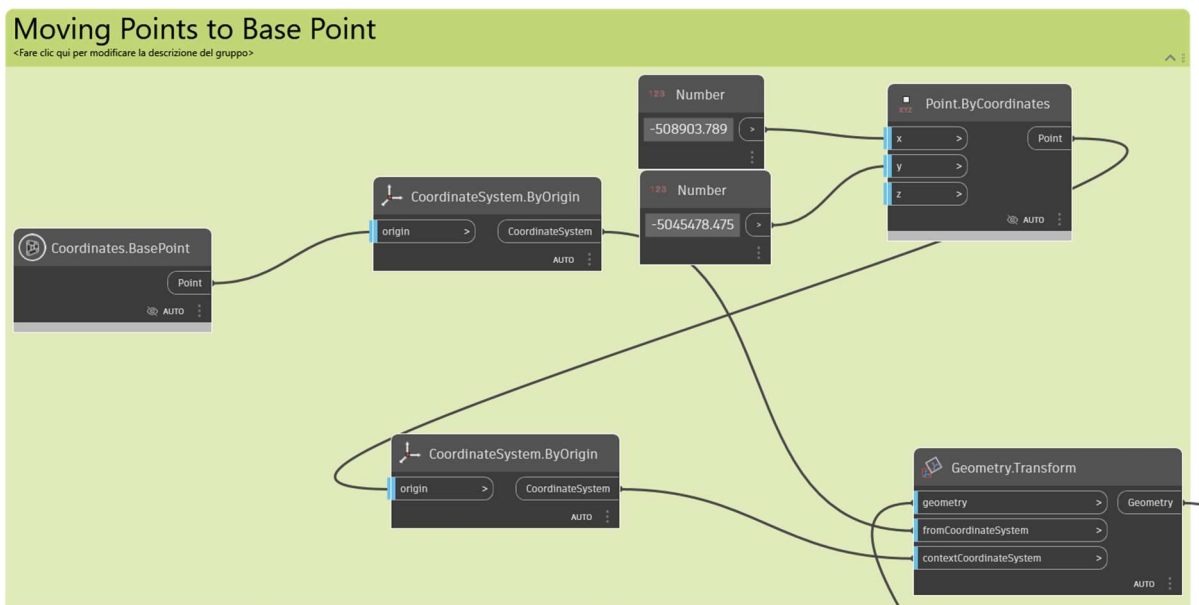
Figure 76 - Group four, moving the points to the centre of view

Dynamo coordinate system is based onto the project base point. So, since the entry coordinates are written as UTM when are translated into cartesian point the geometry will be modelled far away from the focus of the Revit view, even if the project base point is located at the correct site location the dynamo modelling procedure will pass such georeferencing by still modelling far away from it. Also, if the project base point position is changed for any reason or it should be placed in a specific position of the project the script will not be able to place in a correct way the toposurface. To avoid such problem the created points are transformed by moving them of a specific negative value. Such values are the values that Revit will assign to the property "N/S" and "E/O" of the project base point after sharing the coordinates with the CAD of the same toposurface. These values can't be found in any CAD or LandXML file that regard the topographical surface. So, it is assumed that Revit will automatically assign those values as the Centroid of the points composing the surface. The centroid, or the centre of mass, is calculated for each coordinate as the sum of the coordinate divided by their number.

$$N/S \frac{y_1+y_2+y_n}{n} \; ; E/O \frac{x+x_2+x_n}{n}$$

So those values can be found automatically by using the following part of script instead of manual input. As shown in the following picture the algorithm starts by creating three list: x, y and z (even if z were not necessary) to later make summation among them, the number (n) is then easily defined by the number of points, so it is enough to count the number of elements contained into the node that create the geometrical points. The division is done using a code block to correctly define the parameters. Later the two coordinates of the centre of mass are multiplied by -1 to become negative and to be used for the rigid movement of the whole geometry.
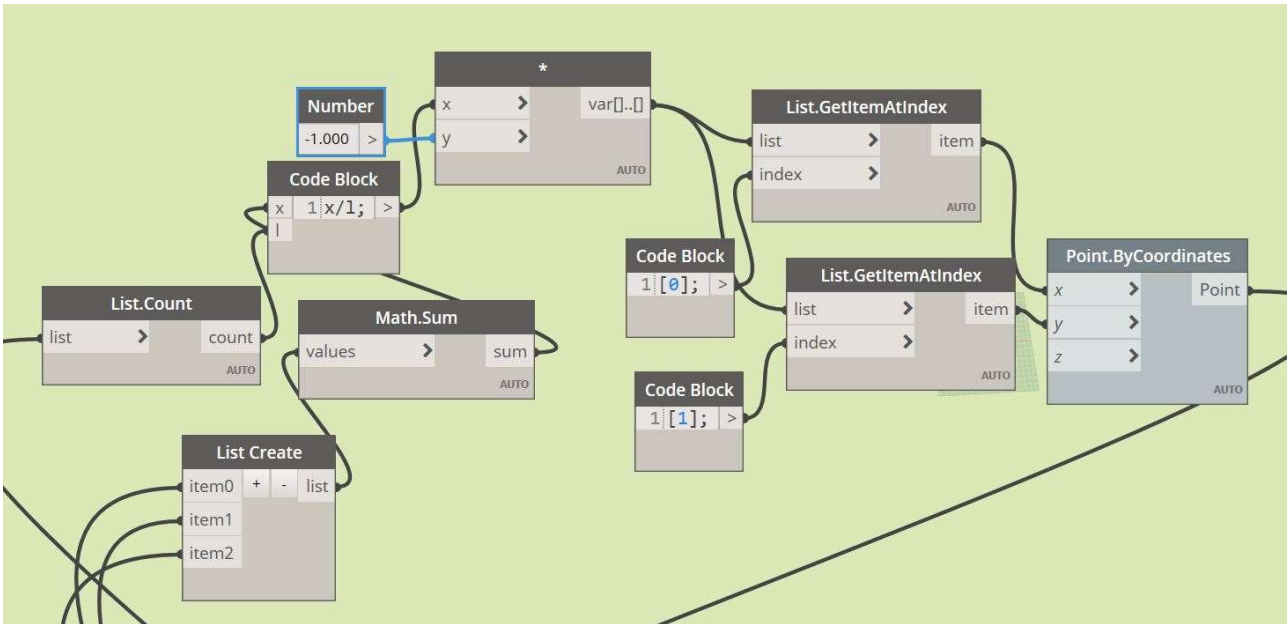
Figure 77 - Centre of mass for rigid movement of the geometry

This process will change the coordinates of the points making some positive and negative values and the one that were close to the centre will have coordinates close to zero. This is not considered as a loss of georeferencing since anything that is processed through the script will follow the same transformation. Also, if the properties of the project base points are well set within Revit any IFC file that will be exported will be still georeferenced. The result that we came up with now is like what the IFCterrain does while transforming the vertices into cartesian points.

Group 5 and 6
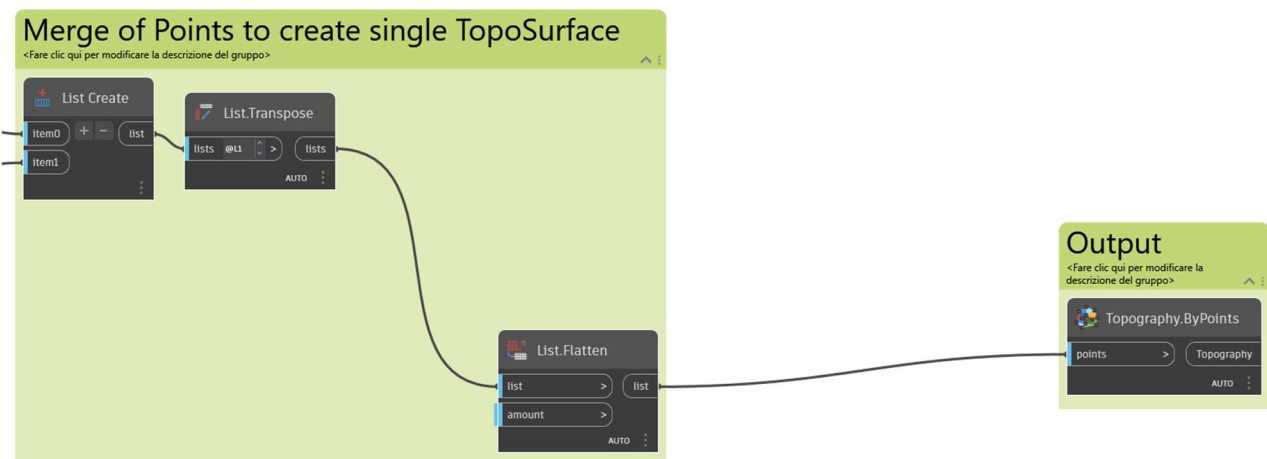
Figure 78 - Group 5 and 6, list merge and toposurface creation

Group 5 is addressed to join the results coming from the mapped surface and the as built surface. By joining the two list we will get a two-element list with all the point nested in it, but this may result in longer processing time. So, it is transposed to then

flatten it to have a single list with all the points included. By merging the list now, we have a single virtual LandXML file that can be processed furthermore if needed, for example we can apply some mathematical simplification or any possible filter after grouping the points.

Group 6 is made by a single node but is the crucial part of the whole procedure, with this node we are including the instance Toposurface within Revit and it will be placed at the centre of the site view. This whole mechanism could have been avoided if such interoperability within a LandXML file and Revit was already existing.

If the previous surface is kept is then possible to calculate the difference in volume. Among the Dynamo Forum there are some examples of how to make a Boolean difference between two toposurface that share the same boundaries.

Usage

Once the script is completed the user can use it without opening Dynamo software again. The dynamo Player present into the manage tab of Revit is a shortcut for running the script at any time during the project and for input data into specific nodes that have been previously selected as "is input" within the canvas.
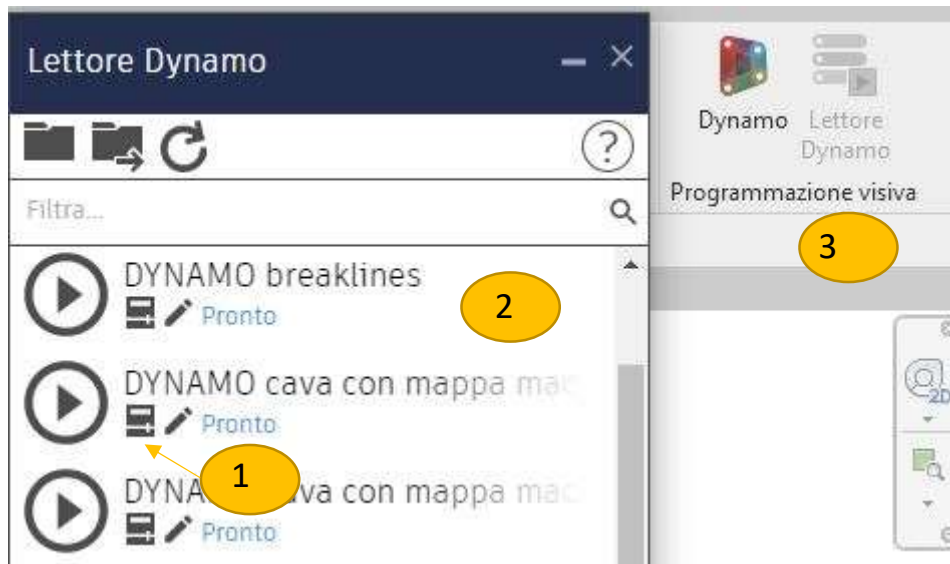
Figure 79 - Dynamo reader interface

In the picture above it is possible to see at 1 the button to access to the "is input" nodes. Number 2 is the overall list of the dynamo script included in the chosen directory, and the play button is to run the algorithm without opening the plug in. Number 3 shows the location within the manage button of the Dynamo player.

The input section accessible through the button number 1 shown in the previous picture will bring the user to the window shown in the picture below.
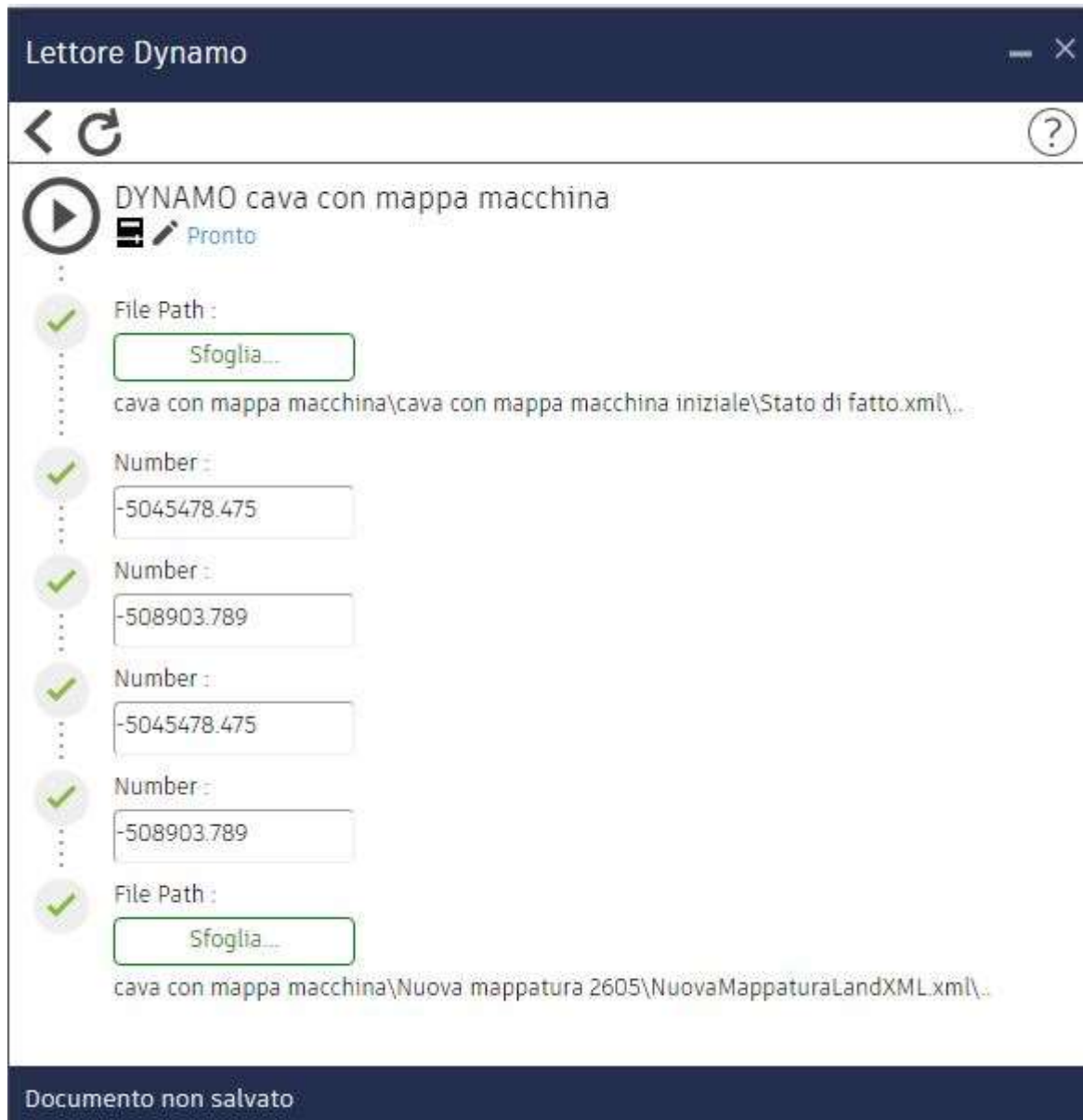
Figure 80 - Section of the inputs of Dynamo Reader

This window is referring to the case without automatic centroid calculation, so the user is asked to insert the numbers that the automatic "share coordinate" is prompting and to specify the file that has to be loaded. Of course, the number to be inserted if the centroid is included will be no longer useful and the file path may be specified only once if the file is automatically replaced within the directory.

The intended workflow that includes this Dynamo script is explained as a diagram in the next picture.
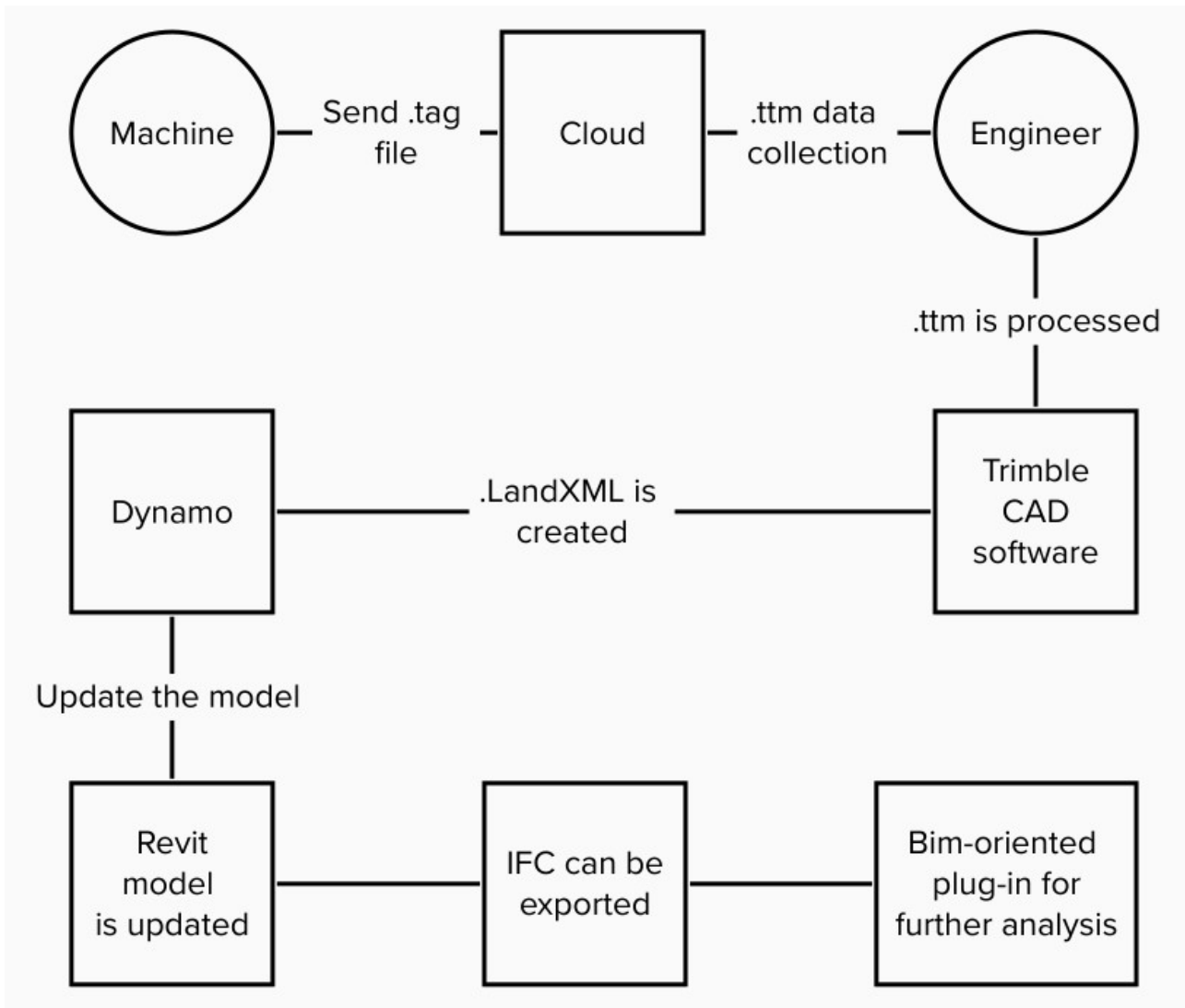
Figure 81 - Workflow with the Dynamo script

This process allows to update the specific instance within a more complex project making the topographical surface part of the cycle just by downloading the file from the cloud and transforming it into LandXML with a simple click. The new software TBC from Trimble already allows to export IFC file, but it couldn't be analysed since the experiment was performed using the previous, but still widely used, version called HCE.

5.3.3 Surface analysis

In this paragraph will be further discussed the obtained results. During the explanation of the Group2 within the previous paragraph it was visible that the three surfaces have different number of points. The initial condition surface has never been retrieved since the professional never modelled it, so for this study it has been used the final design surface to understand the overall site.

To show what the LandXML are describing it is used Civil3D to easily compare them.
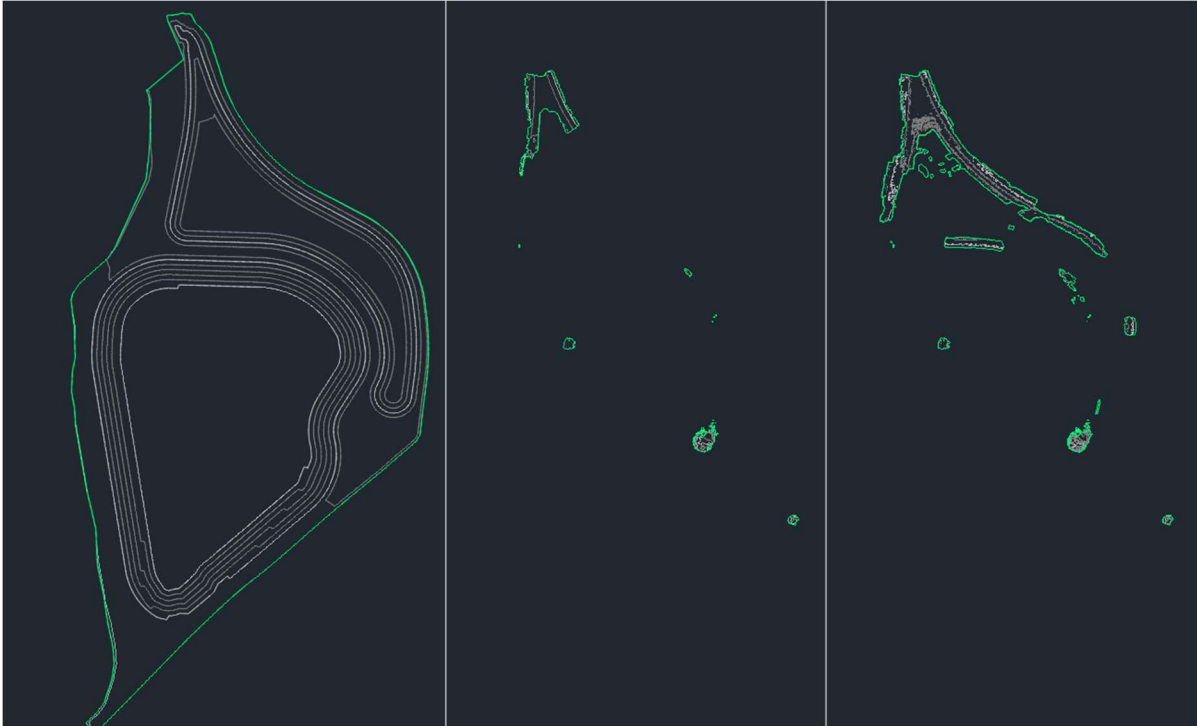
Figure 82 - Design surface (left), First map (centre) and second map (right)

Where if they are imported and georeferenced the interface will look like as follow. So, the files do overlap perfectly.

Figure 83 - Site and mapped surface overlapped

In each surface it is visible its own boundary (green) and the terrain contour (grey) and their properties are the following

File	2D surface (m^2)	3D surface (m^2)	Min. Elevation (m)	Max. Elevation (m)	Triangles	File size (KB)
Design Surface	122967	127073	149.00	163.866	60897	4263
First map (May 10)	2346	3144	147.729	163.148	13133	939
Second Map (May 26)	7137	11307	147.729	163.148	68095	4871

First of all is noted that the minimum height of the design surface is 149 m and the bucket at least once reached an elevation of 147.729 m, this means that for 1.2 m the bucket reached a position that can be not allowed by the project, in case of buried elements and precision work this can be a strong attack to the safety of the worker itself. This result may be due to imprecision in data collection or in an actual neglection of the boundary of the project.

From the numerical result obtained it can be said that the last map retrieved is covering the 5,8% of the total site area and the amount of data in terms of file size and number of triangles are already exceeding the dimension of the whole design surface. The first map is covering the 1.9 %, so means that in thirteen working days there has been an additional 3.9% increase of the covered surface.

The high number of triangles is because the mapped points are retrieved with specific criteria during excavation, so the result is a surface with a lot of irregularities with a shape of pyramids.

Figure 84 - Condition of the surface

A good example of the pass performed by an excavator during digging is given by the picture below.
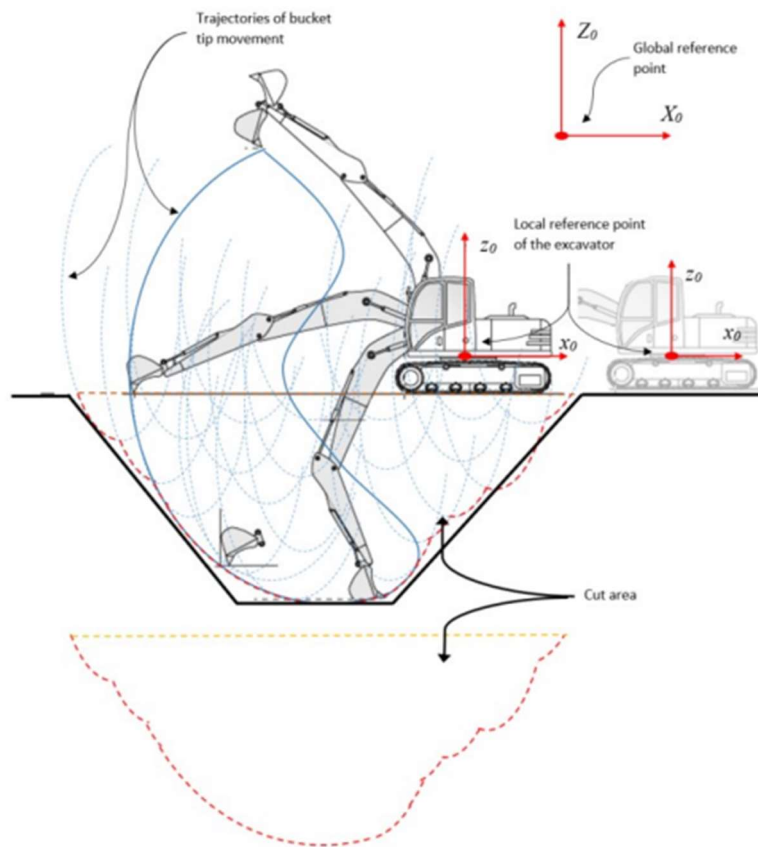
Figure 85 - Pass location of the bucket tip - [48]

For the way the mapping is set all the lower elevations of the tips are collected during time and only the very initial ones are neglected, leaving then some higher points that will then create pyramids encountered into the results.

All this noise should be cleaned by inserting specific simplification rules or by exploring the different mapping rules. During the study of this specific site, it was not possible to test different types of mapping settings. But it is suggested to include human checking within the overall process.

The modelling within Revit environment gave a similar result, the points are well placed and the main volumetry are correctly modelled. A big limit is that Revit will assumes the boundaries of the surface using points placed at similar elevation. Below is presented the result directly from the Revit view.
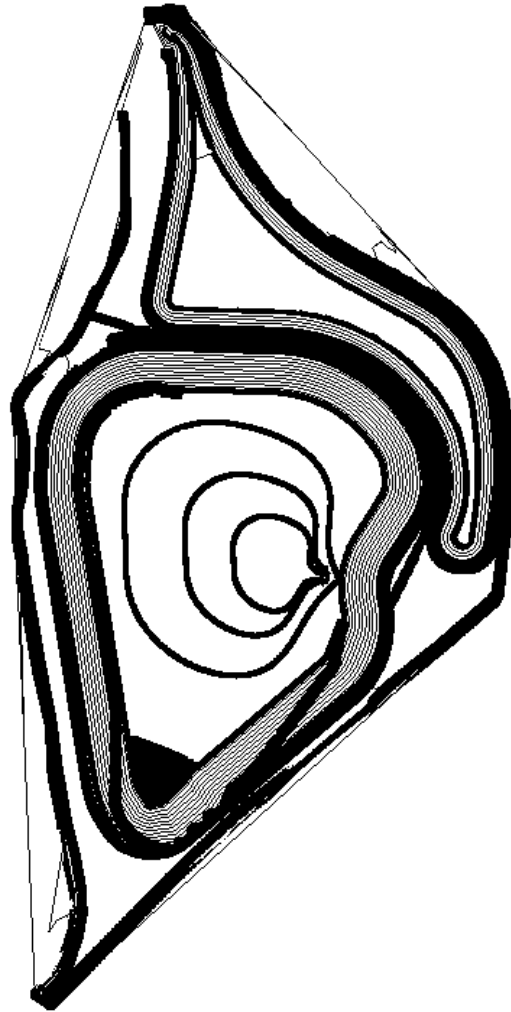
Figure 86 - Overall dimension of the site

Using the script it is imported the first map and it is excluded the merging of the surface in order to study the interpretation of the software about the mapped surface.
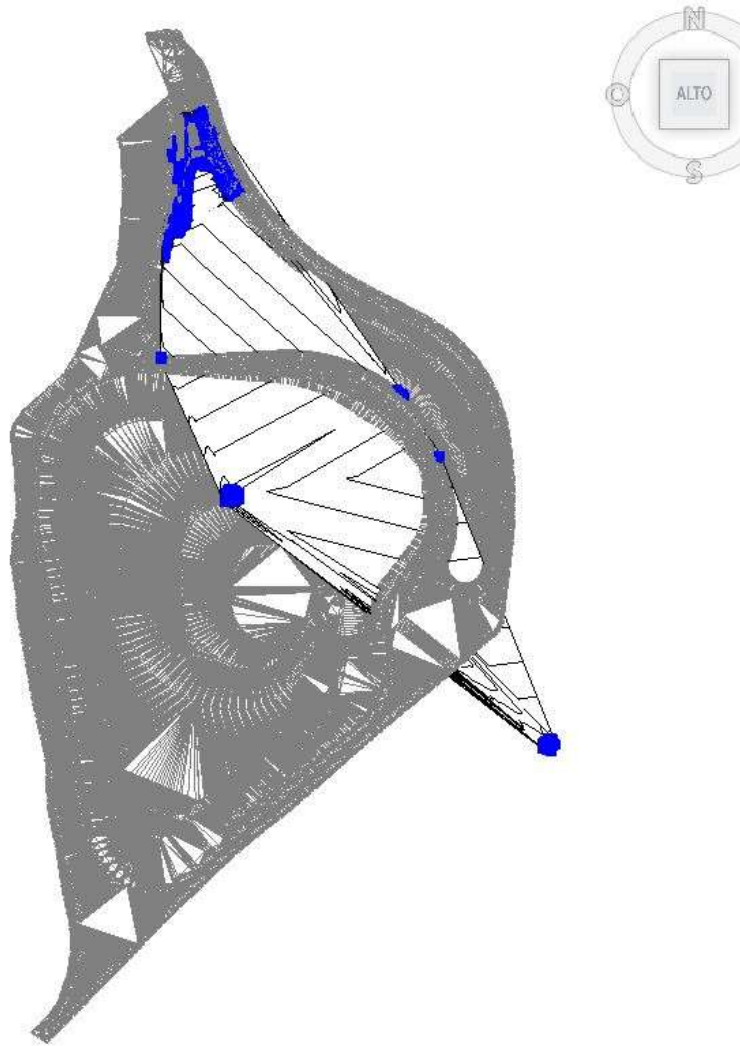
Figure 87 - Mapped points inserted into Revit

Also, here the script acted well on placing the points into a correct position but Revit will not recognise the single areas of elements so it will merge all into a single surface by stretching the toposurface. If then the mapped are included within the list of Cartesian point to generate a single toposurface, such problem will no longer occurs.

Is already visible a clear problem within the usage of such technology.
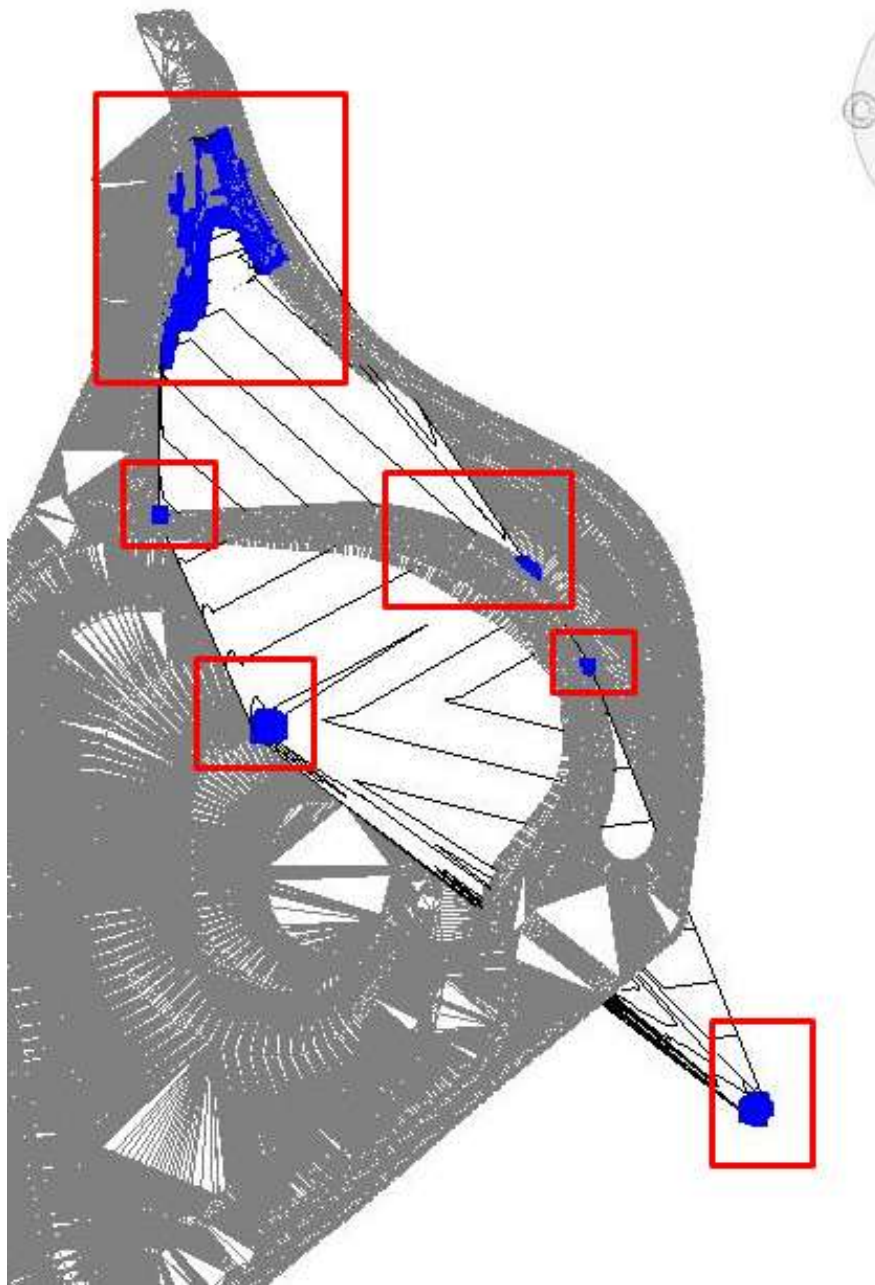
Figure 88 - Mapping out of bound

From the picture below is highlighted where the excavator mapped overall during its working procedure. It is clearly visible that the excavator has been used multiple times in little spots and once also out of bounds. This problem is due to the wrong application of the technology, the operator kept the project active and on mapping conditions while performing works, probably, into a quarry present next to the loaded project. While for the other case can be hypnotized that the machine is used for minor works not linked to a specific completion of a specific area.

The quality of planning the operation and correct usage of the machine result to be crucial for a perfect and automatic map of the surface.

Proposed process

As seen, in case different mapping options will not bring to better result the focus should be placed onto a correct planning of the portion to be excavated and the operator should stick to the indications given by the designer. For the case an excavation for building construction there will be mainly the excavation and more precise small cuts. During the design phase into a BIM environment the area of excavation should be defined geometrically and should be located into specific time span. In this way the operator will receive the portion of project in which he has to work in order to limit the spread of data, then he should be provided with some checkpoints that once reached he should "touch" by mapping them with a provided code. Following this procedure, the overall process can be controlled during time and the productivity can be assessed automatically by retrieving and cleaning the data.

For the case of a forced section excavation the vertices of the parallelepiped may be registered with a predesigned code thus to automatically retrieve them and generate a clean volume within the modelling software.

A similar and strong approach that sees the usage of the machine guidance as a survey robot is provided by M. Hasan [48]. Since the excavators are dynamic machine but when a task is being performed, they stay stationary and will move only after the area is completed. So, an additional man-made check after finishing the target area may be required. The proposed procedure sees the following steps [48]:

1. Set safe radius of working r for the excavator
2. Plan the shortest route to complete job
3. Set first location of the excavator
4. Touch the boundaries of the cut area by mapping the ground level
5. Move towards the initial position of the next area
6. Repeat the step number 4 and continue

Within the paper is proposed a visual scheme to better clarify the process.
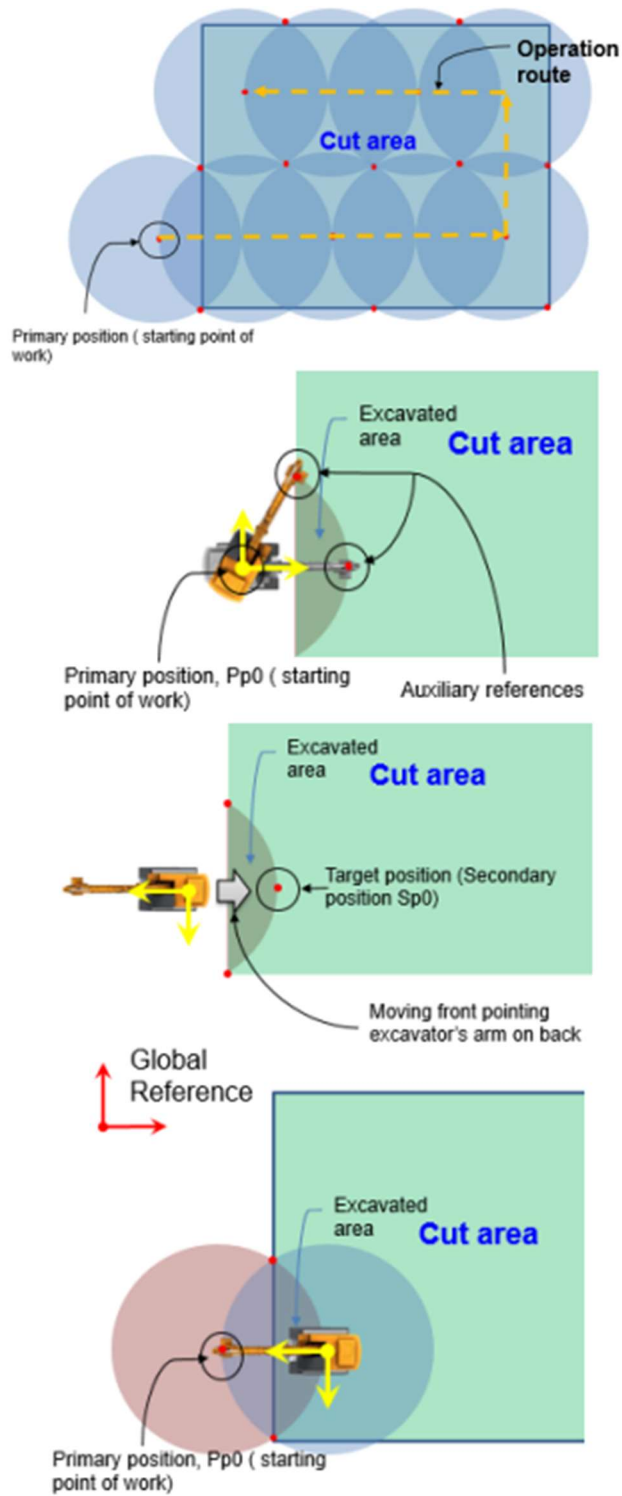
Figure 89 - Example scheme for a front vertical cut – [48]

And this procedure can be also performed for a trench like job.
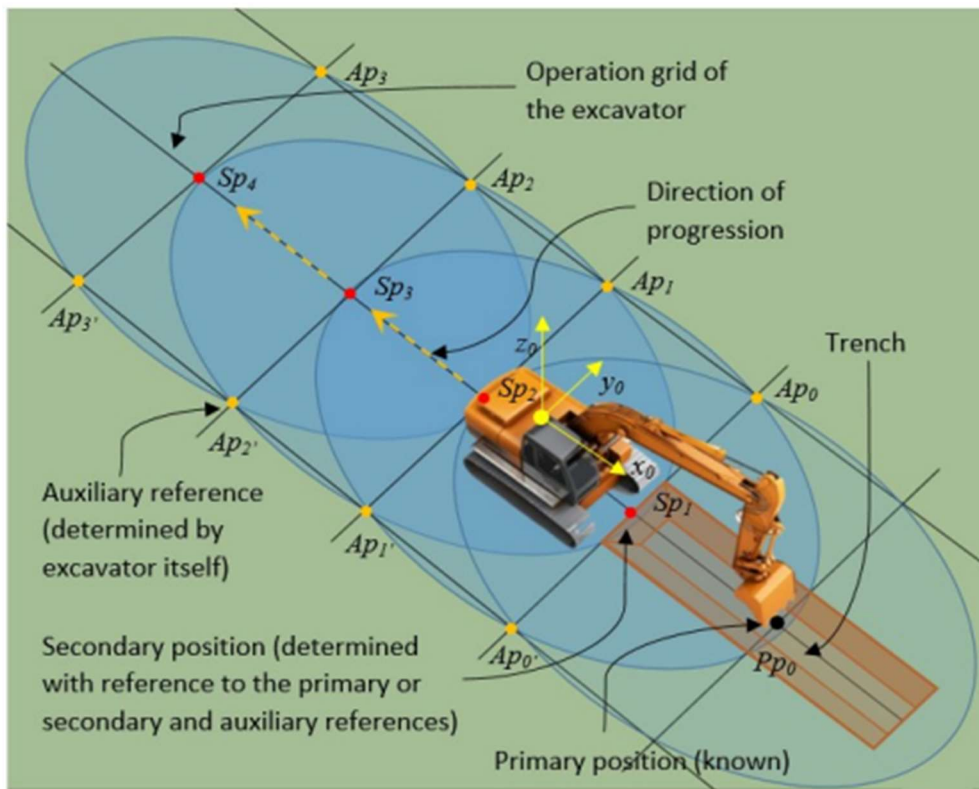
Figure 90 - Trench excavation with manual reference points - [48]

Within a BIM environment this procedure can be easily handled while modelling. Furthermore, having a clear understanding of where the excavator will be placed it will boost the safety condition of the overall site while at the same time improving the control over the productivity without retrieving mapped data that are too much spread among the sites.

Requirements of the approach:

- Attention during planning of the cut areas and excavator rout
- Expert and experienced machine operator that will take part of the survey during excavation
- Clear understanding of the excavator productivity and geometry for correct area sizing
- BIM model able to accept the execution phases
- Precise usage of the machinery without extra and useless mapped areas

5.4 BIM based management of time and space

To include the machinery and the machine guidance within the BIM approach we should make the site and the machine informative. Means that the part of model that is dealing with these two elements should be prepared in a way to be able to accept

the results coming from the field and from the report automatically exported. The data that will be consider are mainly referring to the productivity and to the cost and time that have been spent to perform specific operations and are the one exportable from the machine (DTM and Productivity files). To introduce the results of the machine within the BIM model we may use two ways: insert the data into calculation or database by means of interoperable data exchange between the civil platform and the main model or we can also include the 3D model to which we will assign a series of parameter. Some of the parameters are properties of the machinery itself and may be fixed, or manually changeable, for example the overall dimension will not change but the capacity of the bucket may be changed between operations. Other parameters are then assigned to the machinery but are referred to the process, so they are not mechanical properties, the values that will fill such parameters are time or space dependent, which will become hard to manage within Revit. So, the overall data collection and initial processing should be done with plug-ins or external software. For example, the fuel consumed during a process is keep being exported by the machine, so we may calculate the total consumption among a range of time and then assign it as a property of the process.

The geometric properties are implicitly included within the 3D model of the excavator, but they may be also expressed as an IFC parameter. For instance, the dimension will be crucial to define the safety radius while positioning the model within the site areas. The visual check during desing can be performed similarly to how it is done for the tower crane. An example of application is given by Schwabe K. et al. [50].
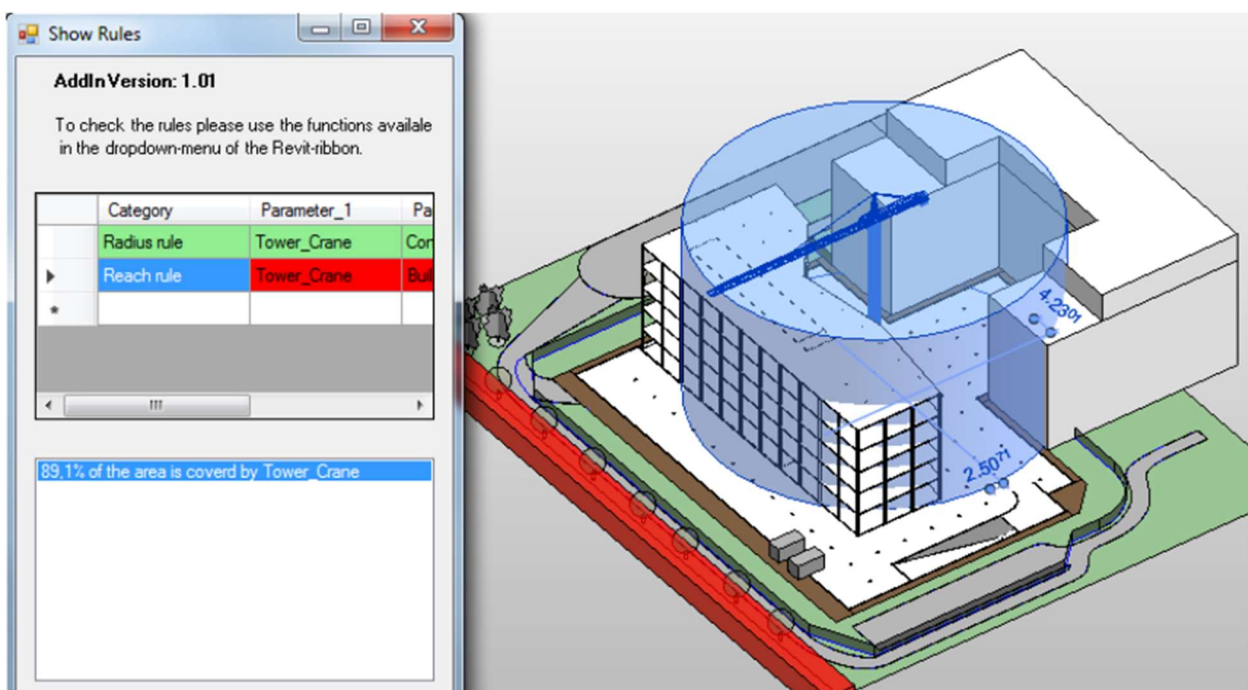
Figure 91 - Radius of action for a tower crane - [50]

Such plug in can be used for planning the site layout, it may be integrated within the BIM database a set of rules such as, number of entities to be positioned, automated calculation of shortest route for the vehicle and so on. While to choose the correct number and size of equipment during the design phase, the BIM database should be filled with the rules of dimensioning (for each piece of equipment) similarly to the one presented within the paragraph 4. Then the information about the work to be performed are also included into the database and can be used to assess and forecast the result of the decision.

Then the site to be informative, it must be divided into functional areas (coded with their SBS structure) where the machinery will roam and work. The single areas are should well divided and surrounded by a "geofence". The geofence is a virtual delimitation of the spaces and the equipment, if provided of the machine guidance, can recognize its boundaries while performing an operation. Such geofences are useful for the safety of the process and for identify in space the specific tasks. For example, the file "cycle data" coming from the machinery can provide the type of work that is performed during a known time and in a known location but for the excavator the operations are named: Other, roaming on road and idle. For the sake of clarity an example from the case study is provided below.

Report Generated Date: 16/06/2022 11:32:46 UTC										
Start Time (Europe/Ror	Operator	Cycle Name	Total Cycle Time(s)	Cycle Fuel (L)	Moved Payload (t)	Start Lattitude	Start Longitud	Destination L	Destination L	Macchina vuc	M
10/06/2022 07:56:09	Operator example	In attesa	18	0,0276	0	43,15462494	11,27873135	43,15462494	11,27873135	18	0
10/06/2022 07:56:27	Operator example	Altro	98	0,7542	0	43,15462494	11,27873135	43,15462494	11,27873135		
10/06/2022 07:58:06	Operator example	In attesa	97	0,1077	0	43,15461349	11,27877426	43,15461349	11,27877426	97	0
10/06/2022 07:59:44	Operator example	Altro	8	0,0842	0	43,15458298	11,27875328	43,15458298	11,27875328		
10/06/2022 07:59:52	Operator example	Circolazione su strada	10	0,1307	0	43,15458298	11,27875328	43,15458298	11,27875328		
10/06/2022 08:00:02	Operator example	Altro	7	0,1053	0	43,15458298	11,27875328	43,15458298	11,27875328		

Figure 92 - CAT Advance productivity Cycle data sample

So, it is impossible to understand which kind of operation was performed and for how long. This problem may be solved by localising the activities.
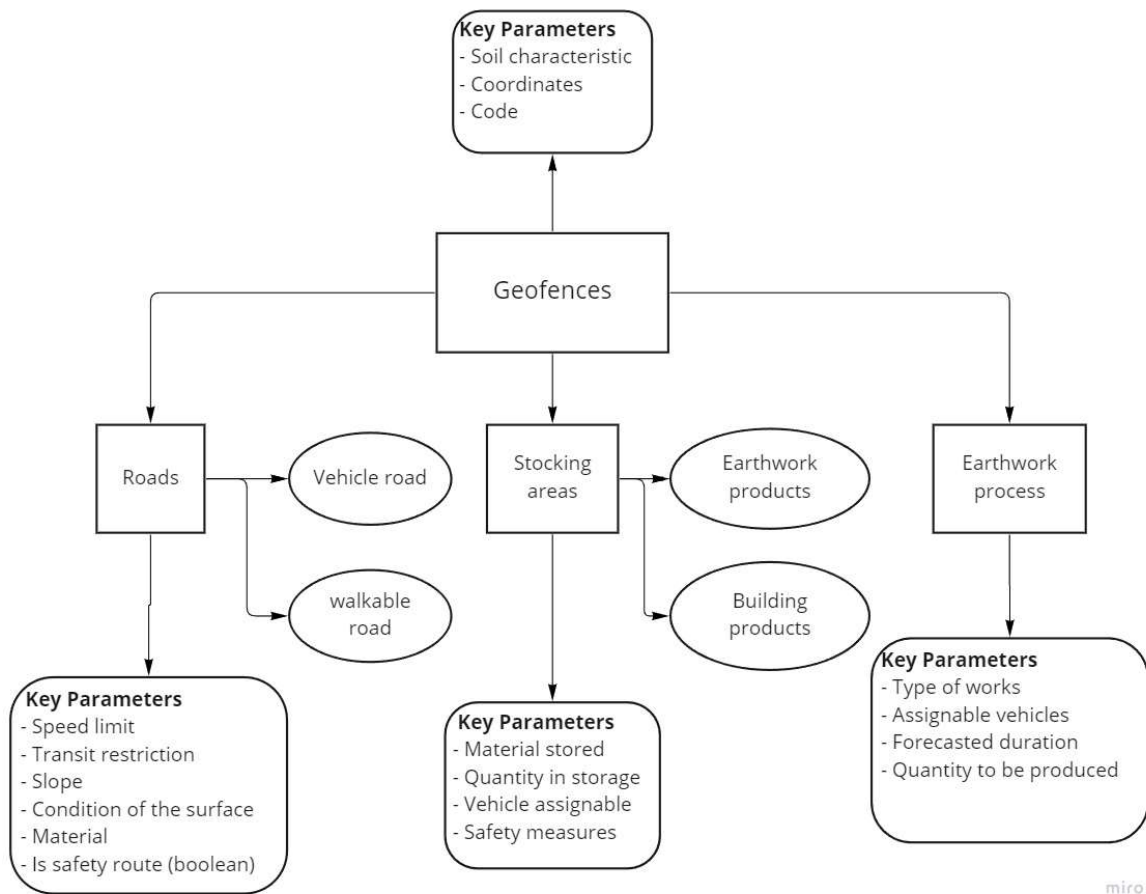
Figure 93 - Geofence Types and parameters

Since the equipment is constantly tracked when a reported operation will coincide within a specific area it will be quasi-automatically recognised its type. For the IFC translation of the earthwork elements and entities it will be referred to the part 6.6 of the schema 4.3.0.1 under the category IfcSharedInfrastructureElements

Geofence – Roads

The viability of the construction site is an important topic because if the roads are well maintained and designed, we are guaranteeing a good efficiency, safety and easiness of navigation. The type of road may be divided within the walkway and the vehicle roads. By creating a dedicated area to road, we can group the information regarding each single road. During the design phase it may be required to add these areas and their function to the suitable breakdown structures, the vehicle or workers that can transit, the speed limit, the slope, the material and the purpose of the road (e.g., safety route). The preparation of the BIM model should be performed with the aim of using a BIM-based software that can control the site in real time or with a good frequency of updating. The data coming from the machine about the cycle "roaming on road" may be now interpreted by reading the registered coordinates, whenever the coordinates are coincident with a Geofence of a road branch the data can be

considered reliable. Then by keeping track of the road conditions by means of a parameter "Surface conditions" is possible to merge the information about the last time a steam roller (or dozer) refurbished the path or by integrating also the water cannons when it was the last time the dust production have been controlled.
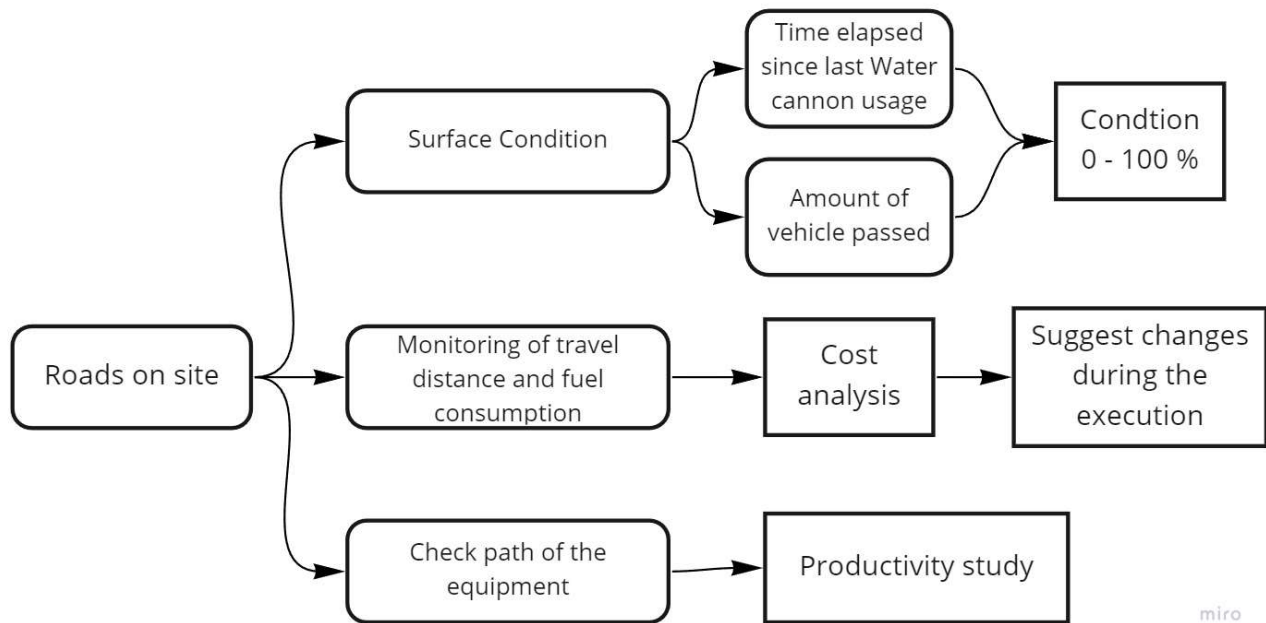
Figure 94 - Geofence Road

So, knowing the road usage about the overall process may help to further identify if the designed layout of the area was optimal or if any changes may be required. Lastly, if the workers are also tracked the safety of the viability within the site will improve drastically.

To implement the concept within the IFC schema it is proposed to use the entity IfcCourse, located at point 6.6.3.2, which type is then described and enumerated by IfcCourseType and IfcCourseTypeEnum. The usage of IfcCourse is perfect for our purpose, it lays at the same level of IfcBeam, IfcColumns and all the other entities that inherit from IfcBuiltElement. The description given by the BuildingSMART is the following, *"A built element whose length greatly exceeds its thickness and often also its width, usually of a single material laid on site on top of another horizontal or nearly horizontal built element. A course is distinctive from a earthworks element in that a course is a graded granular (which can be bound or unbound) material that is generally processed in some fashion, where as earthworks elements are soil earthen based structure that can be formed by removal and transport of general ground material. (...)"* [11]. Important property set identified are then Pset_Condition, Pset_Maintenance, Pset_ServiceLife, Pset_CourseCommon. Of course, other parameters may be required about maintenance and information. To the definition

of the course then it may be added the definition of the built element, if needed, IfcPavement defined as *"Type of built element in a road or other paved area to provide an even surface sustaining loads from vehicles or pedestrians, usually comprising several courses. NOTE Definition from ISO 6707-1: road, runway, or similar construction above the subgrade."[11]*, that is also comprised under the entity IfcBuiltElement.

Geofence – Stocking Areas

Stocking areas can be defined for both the earthwork material and the building products. By focusing onto the earthwork process the stocking areas are required since the very beginning of the process, the cleaning of the plant layer. Such areas can include the material extracted or the material imported from quarries or bought from producers and can be brought in place mainly by the wheel loaders or by the dumpers. This area is crucial for the management of the resources, because the material that is not directly brought outside of the construction site is stored. Important during the design phase is to design it proportional to the quantity that will be excavated multiplied by the swallowing coefficient of the loosen material. The process of integration of the technology is a bit complicated since the machine guidance and the sensors are primary designed to increase the productivity rather than work over the management point of view. But, for the stocking areas the situation is different, the Advance productivity application of CAT provide a full report about the material moved and stored. To remind the structure is again reported a sample below.

Report Generated Date: 16/06/2022 11:31:01 UTC

Bucket Payload Measu	Bucket Payload Sequer	Bucket Payload (t)	Truck Store Time/Date	Truck Total buckets	Truck Payload (	Operator Descr	Material Id	Material Descri	Truck Id	Truck Descriptio
08/06/2022 13:25:39	1	0,62	08/06/2022 15:00:07	157	375,98	Operator Exam	16777216	CAL070	16777216	IVECO
08/06/2022 13:26:01	2	2,9	08/06/2022 15:00:07	157	375,98	Operator Exam	16777216	CAL070	16777216	IVECO
08/06/2022 13:26:24	3	2,88	08/06/2022 15:00:07	157	375,98	Operator Exam	16777216	CAL070	16777216	IVECO
08/06/2022 13:26:43	4	1,54	08/06/2022 15:00:07	157	375,98	Operator Exam	16777216	CAL070	16777216	IVECO
08/06/2022 13:27:03	5	1,98	08/06/2022 15:00:07	157	375,98	Operator Exam	16777216	CAL070	16777216	IVECO
08/06/2022 13:27:27	6	3,1	08/06/2022 15:00:07	157	375,98	Operator Exam	16777216	CAL070	16777216	IVECO
08/06/2022 13:27:49	7	2,15	08/06/2022 15:00:07	157	375,98	Operator Exam	16777216	CAL070	16777216	IVECO

Figure 95 - CAT Advanced Productivity Material summary sample report

The machinery is already available to receive data that can be conformed to the scheme and codes adopted by the BIM process. It is necessary to refer to the truck description and ID with the one assignable by the OBS (Object Breakdown Structure) and in case of a pile there will be the code for the desired pile area. So, the manager of the fleet will input within the machinery the possible destination of the materials and during the process the machine operator is required to take care about the correct data collection. In this way is numerically possible to keep track of the material moved and where is located. By entering the data within a central database, the stockpiles can be updated in volume and with percentage indicators (0 to 100) is possible to control the actual availability of the material or threshold of disposal.
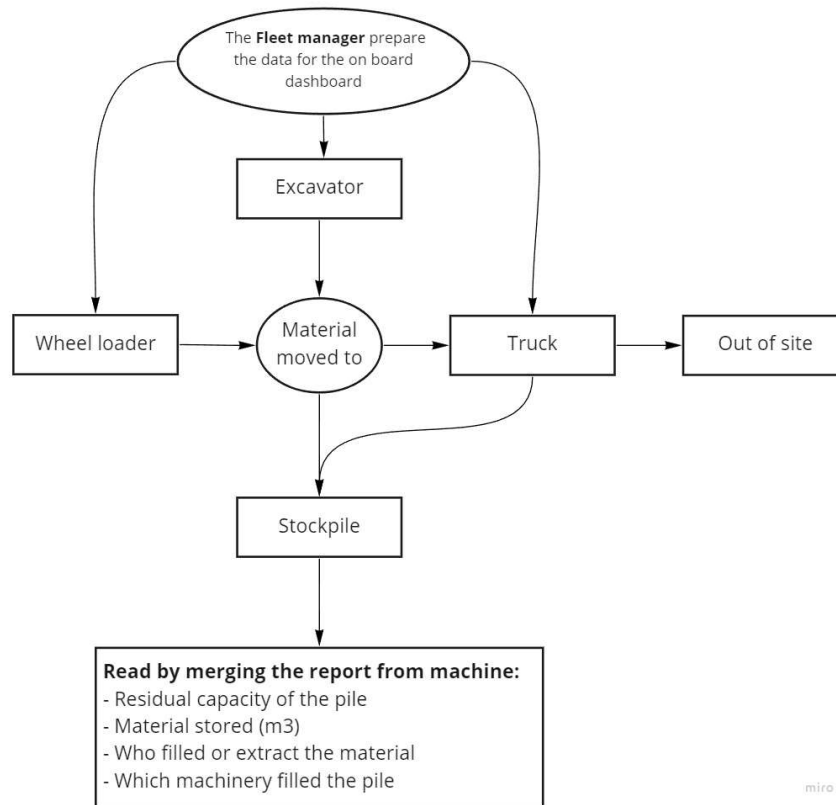
Figure 96 - Geofence Stockpiles linked workflow

The report that allows the storage of data about the stockpiles are written in csv so are easily interpretable by any software or plug in that will manage the data entry.

The IFC translation is then provided by the usage of the entity IfcEarthworksFill defined as a type of earthwork element that is built to subgrade or raise the level of the ground. This entity is particularly useful for the purpose of describing a stockpile, because among the IfcEartworksFillTypeEnum there is the possibility of being "user defined". Its quantity is collected within the quantity set Qto_EarthworksFillBaseQuantites where the Length, Width, Depth, Loose/compacted Volume can be described. The quantity that are supplied for validating the correct interpretation of the body shape representation while import are then included within the Qto_BodyGeomtryValidation, where for each parameter the schema gives also the explanation of the calculation of the properties.

Geofence – Earthwork process

Within this Geofence all the earthwork process will take place, for additional accuracy this area that now we name "Earthwork process" can be furthermore subdivided within all the possible types of earth movement. The involved heavy machinery are not only excavators and the main that we can identify are:

- Dumpers
- Wheel loaders
- Dozer
- Excavators
- Steam rollers

By mentioning these pieces of equipment, we mostly cover the overall process of earth movement. It is worth remembering that each machine can be equipped with machine guidance. The main activities analysed which involve the usage of the fleet are summarised within the following table.

Machine	Work
Dumpers	Import/Export of material
	Movement of material within site
Wheel loader	Transport of material
	Pile/truck loading
	Grading
Dozer	Grading for road forming
	Ground levelling
	Slope creation
Excavator	Cut/fills
	Lifting of other objects
Steam Rollers	Compaction of the ground

Thanks to the extension of the schema, it will be possible to refer to the equipment by means of the following part of schema.
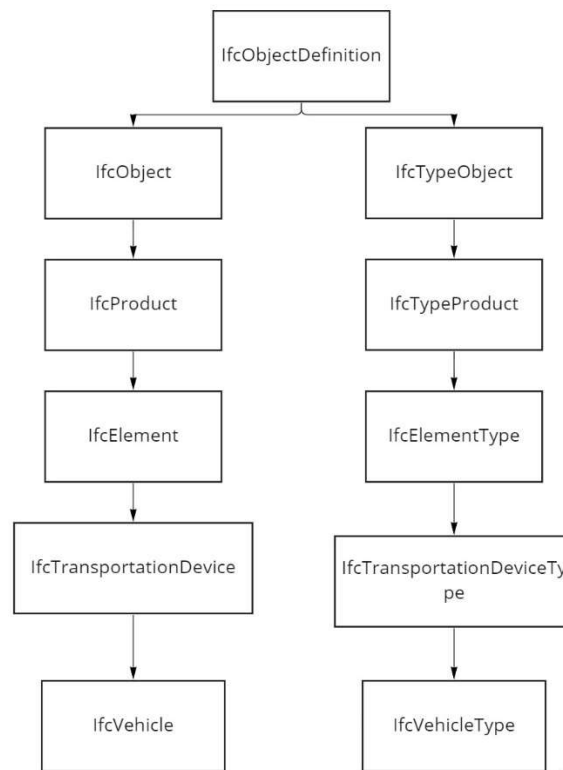
Figure 97 - Definition of vehicle using IFC 4.3

The schema already provides a wide set of property sets to be used that of course may be amplified by adding custom parameters.

Within this area of the site the data that may be used are the mapped points and the cycle data. The mapped surfaces that have been analysed for the excavator represent the most complicated case since they consist in the most dynamic and diverse machinery, but for a wheel loader, a dozer, a truck and steam roller the mapped surface can be retrieved easily. So, all the process of compaction, transport and grading can be automatically managed. The surface graded by the dozer (or motor grader if used) can be automatically generated by exporting the data of the specific geofence and merge the points with the site toposurface (for example by means of the Dynamo script), unluckily for the case study it hasn't been possible to try the result of the map coming from a dozer or motor grader. The steam roller will easily export the pass count and the location work, then by mean of built-in plate test it will assess the quality of the work. Wheel loader and damper entering the geofence will be then used for double check the material that is moved and assessed by means of the computer aid 3D volume calculation. The data that are linked to modification of the terrain are so linked to the GIS system and will be considered reliable when the data collection will be proven reliable.

The cycle data then includes the time of the cycle and its parts, the name of the operator, so it is possible to link to the area all the operator that take part in the process, and the fuel consumption.

We can see the Geofence – Earthwork process as little database of the history of the work and its current state. To express in a clear way what is the process intended the following chart is proposed.
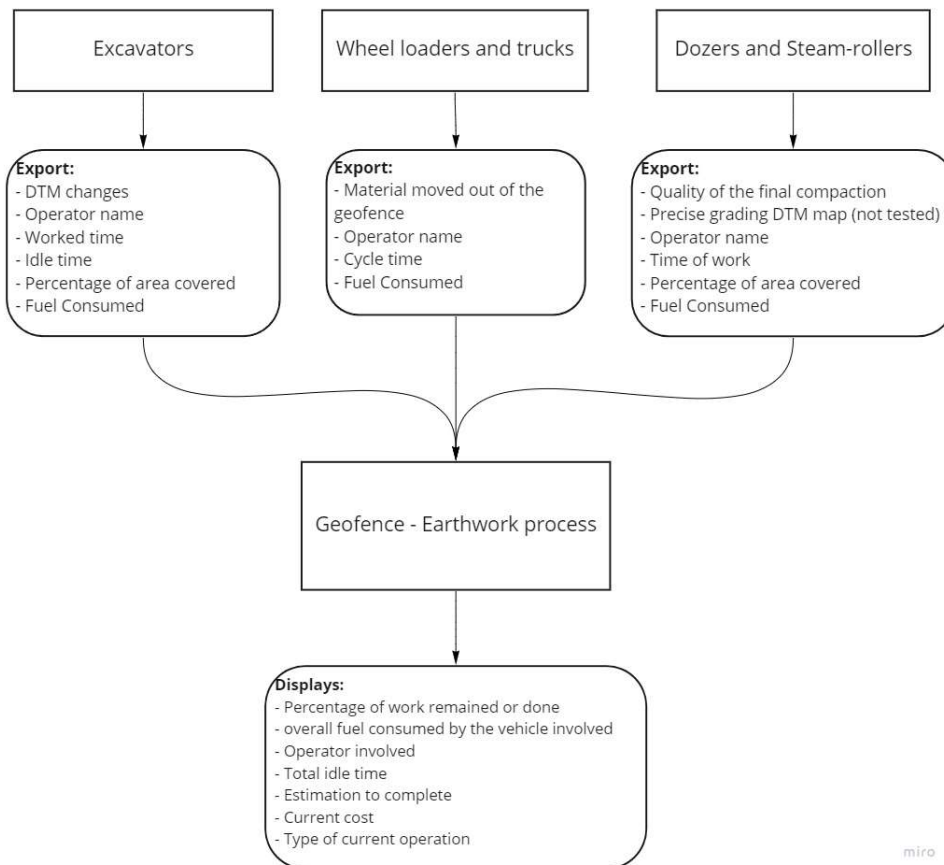
Figure 98 - Geofence - Earthwork process, intended output and workflow

Thanks to the results coming from each area the works director can then update the diary of the work manually or with the aid of a BIM oriented software.

As suitable IFC entities it is identified IfcEarthworksCut that is defined by the standard as the resulting void from modification of existing terrain by excavation or by other means of removing material, its definition differently than IfcEarthworksFill goes to the branch of IfcFeatureElementSubtraction. Its types are listed within IfcEarthworksCutTypeEnum and it is also admitted a user defined one.

It is then worth to mention a study carried out by A. Hammad et al. [49] about the usage of machine guidance for management in real time of the fleet and of the overall productivity. The study performed in 2013 is referring to the first version of machine guidance and localisation and is not aiming to an integrated BIM approach. What is

interesting in their approach that have been taken as idea for this thesis is the division of the site in functional areas for identification of the processes. Then they proposed a new architecture of the process based on a multiagent system that will coordinate the fleet operation in real time. The case study proposed by them is to set a scaled scenario for then retrieve positioning and process data to analyse the history of the movement for productivity analysis. An image about their case study is proposed below.
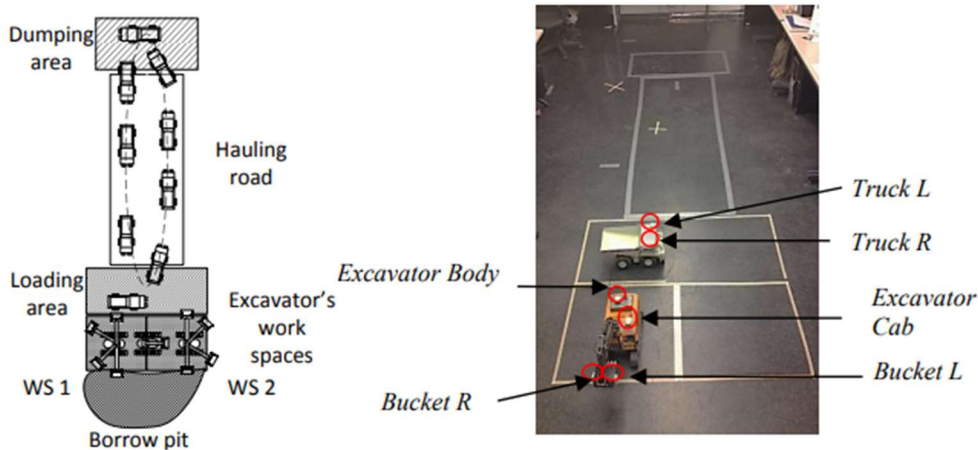
(a) 2D model of the case study

(b) A picture of the actual case study, UWB tags are marked on the picture

Figure 99 - Site division for activity recognition - [49]

The subdivision in areas of the site is also improving the overall safety of the operations. By localising the works within the geofences we are then visually creating areas with specific risks that are linked to the sum of the machine, workers and process present in the area. So, within the database of information that are linked to the areas is possible to include the knowledge included within the PSC written during the design phase.

As a conclusion a diagram with the IFC entities that may help into the development of an interoperable model.
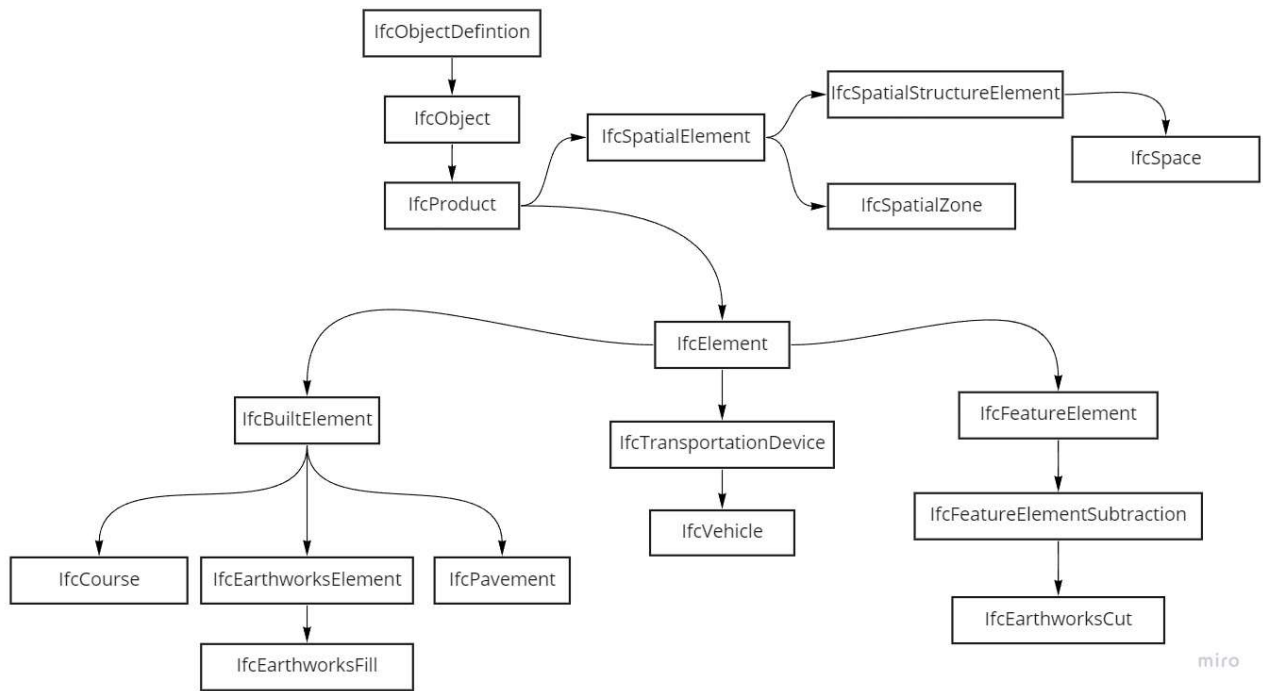
Figure 100 - IFC scheme for site and process management

5.5 BIM-based quantity take-off

To perform a BIM QTO the model should be prepared and organized in a way that the BIM calculation tool can collect the specific quantity, if the model is not designed for QTO the results may be misleading. Such procedure may be done with Revit schedule or with an external software. If the calculation is done with Revit the model has already its own internal organisation so no further export may require if not for the result. But QTO usually is done for the whole disciplines so having a shared environment where the earthwork quantity can join would be a better solution. The aim of this query is to extract the quantity for preparing the estimation for tendering and for update the as built documents and by the end of the construction site to have full history of the work executed to prepare the final bill. According to the DM 48/2018 the works direction should control the cost linked to an execution of a construction work by emitting precise accounting documents with regular and predefined interval.

The main quantities linked to the earth movement and that has to be extracted are:

- Volume of earth moved (cut/fills)
- Fuel consumed
- Worker salary/time
- Hour of Rent
- Material sold or bought (stockpiles deltas)

The IFC schema provide a solution for quantity exchange between platforms. The entities are called IfcQuantitySet and are positioned under the IfcPropertySetDefinition.

Entity inheritance
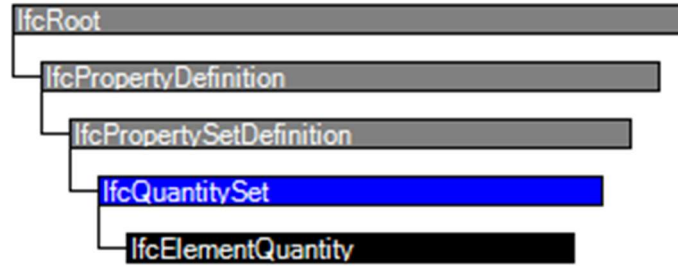
Figure 101 - IfcQuantitySet Inheritance - [15]

This entity is an abstract supertype for all the quantity sets attached to objects according to BuildingSMART [15] *"The quantity set is a container class that holds the individual quantities within a quantity tree. These quantities are interpreted according to their name attribute and classified according to their measure type. Some quantity sets are included in the IFC specification and have a predefined set of quantities indicated by assigning a significant name",* the quantity sets that can be applied to a specific object are listed within the object specification. This entity so is like the Property set, it works as a container of simpler definition, the element IfcElementQuantity, which can have also the subtypes of IfcPhysicalQuantities and are shown in the graph below.
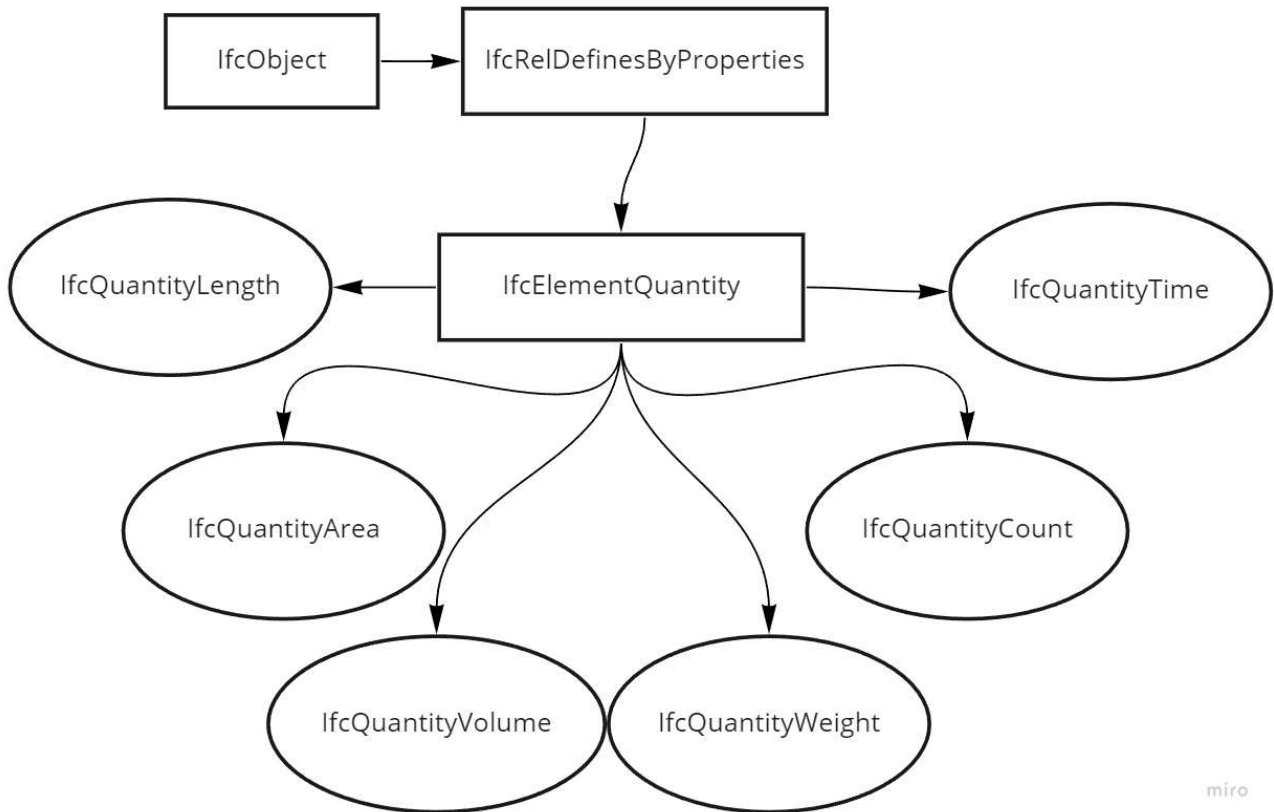
Figure 102 – IfcElementQuantity definition

To end the translation into IFC language we may need some quantity sets to be applied to the earthwork elements and the process. Again, the IFC schema 4.3 forecast a series of QTO sets and are specified within the object specification, the most relevant are

- Qto_VolumetricStratumBaseQuantities
- Qto_SurfaceFeatureBaseQuantities
- Qto_PavementBaseQuantities
- Qto_EarthworksFillBaseQuantities
- Qto_EarthworksCutBaseQuantities
- Qto_CourseBaseQuantites

Since the parameters linked to the machine and the productivity are time based the calculation should summarize what have been collected from the equipment and create a sort of "Picture" of the situation at a specific time. Revit schedule is not perfectly suitable for this kind of time-based data. With the newer version is in any case possible to use Key Schedules to link an object to multiple data. For this case study it is suggested the development of a plug In or a software that will manage the database and calculation.

Referring to the paragraph of the discussion of the exported reports we can now use the quantities contained within the excel files and integrated them within the BIM process.

Material Summary			
ID	Parameter Name	Data Type	IfcQuantity
M02	Bucket payload sequence	Integer	Count
M03	Bucket Payload (t)	Float	Weight
M04	Truck Store time/Date	Date and Time	\
M05	Truck total buckets	Integer	Count
M06	Truck Payload (t)	Float	Weight
M07	Operator Description	String	\
M08	Material ID	Integer	\
M10	Truck ID	Integer	\
Cycle Data			
ID	Parameter Name	Data Type	IfcQuantity
C02	Operator	String	\
C03	Cycle Name	String	\
C04	Total Cycle Time	Integer	Time
C05	Cycle fuel (l)	Float	Volume
C06	Moved Payload (t)	Float	Weight
C11	Machine empty and stopped Time (s)	Integer	Time
C13	Drive – Time (s)	Integer	Time
C14	Drive – Distance (km)	Integer	Length
C15	Various – Time (s)	Integer	Time
C16	Various – Distance (km)	Integer	Length

The parameters that are not categorized with any IfcQuantity are then useful for link the data to the specific worker, cycle, material and storage (remembering that truck ID parameter is used by CAT also when referring to stockpiles).

For the process of quantity take off we can refer to what have been said in the paragraph 5.4, the advantage of having the site divided into areas that also works as database of the history of the works performed in that area, we can then set a workflow for the QTO as shown below.
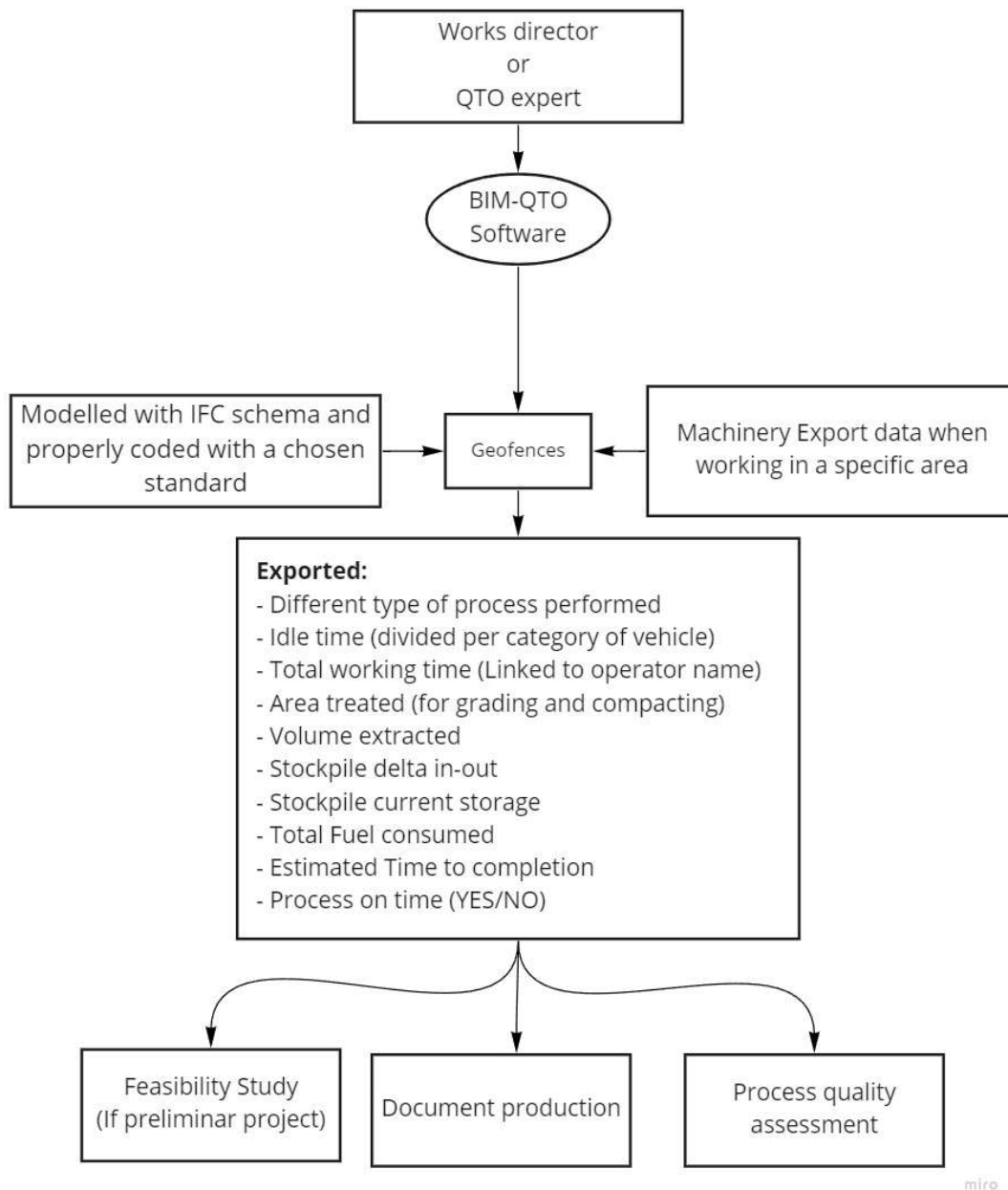
Figure 103 - QTO integration within the process

The idea is to collect all the data generated by each machine of the fleet that is working among the geofences. Then the data linked to the work executed are labelled trough an alphanumeric code that is characteristic of the specific earthwork (can be the WBS code). Lastly the activities are populated by a series of parameters and data that are descriptive for them or that can help to recognize the worker, machine, location and so on. In this way for the final QTO is possible to group each process together or leave them as a list of what have been done, with their relative quantities. The summary is important if then is needed to prepare the mandatory documents that are required during the construction site, such as the SAL, the measures book,

the process diary and so on. The results are then kept and collected for the accounting register and for the final summary of the bill related to the construction

The QTO can be used also for other studies other than creating reports about the as built conditions. For example, it can be used to make an estimation of the remaining work based on the productivity achieved until that time, check the idle time of the machinery and point out the weak point of the overall production and record the data for future tendering.

An extra diagram is given to provide a clear example of the possible integration of the machine guidance results within the proposed approach. The following scheme describe the logical path of the "Geofences database" and clarify the information workflow described earlier.
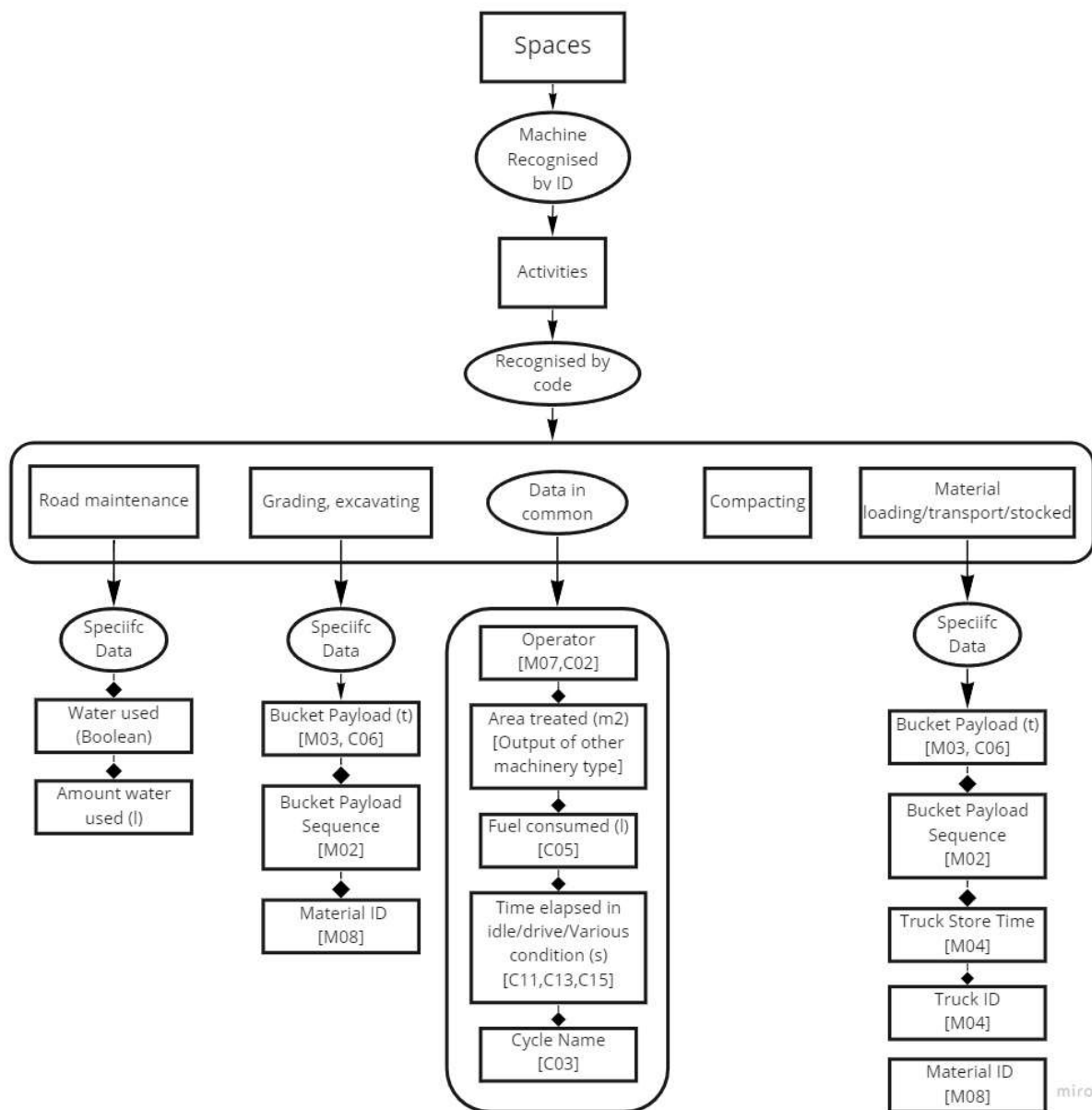
Figure 104 - QTO data retrieval and organisation

5.6 BIM For safety - Preparing the model information

Safety of the construction site should be kept during all kind of operations, the dynamicity of the process due tools usage and people roaming makes complicated the processes of control and prediction. Furthermore, the situation become worse if are included also the earthworks heavy machinery. Nowadays the machines are equipped with sensors and alarms that can detect the workers that are standing in the proximity of the vehicle and will send warning (visual or sound) so the risk of running over a pedestrian can be reduced on site. But safety should be ensured by preventing the accidents by assessing the risks, perform a correct design and by providing a correct control during the execution. For sake of completeness of this paper is worth to spend some pages on the discussion about BIM, safety and machine guidance.

According to the Italian law the PSC should be created for all the works, except for emergencies, rescues or when there is only one operative company. Inside of this document are collected and organised in chapters all the risks that are linked to specific works, equipment and areas. It is also mandatory to provide the time plan of the works and then to provide the risks linked to the clash between two operations that will be performed at the same time. As already introduced the PSC is drawn up during the design phase with the presence of the CSP and then during construction the works director and the CSE will ensure that it will be applied as planned. Furthermore, the document may need to be updated and modified, with the supervision of the CSE and the approval of the client, in case of delays or other internal/external influences.

This document is so an important source of knowledge about the risks that the overall construction site carries. As we introduced within the paragraph 4.5.1 the main risks that are linked to the earthwork equipment is dependant to the type of work performed and the surrounding environment and operations.

In addition, for a complete BIM model it may be required the development of a 3D BIM oriented models of the machinery thus, to link the specific parameters related only to an actual BIM instance existing in the virtual workspace. An interesting study about the modelling of an excavator is provided by S. Moon and J. Seo [76], but for technical reasons is not further explored within this thesis.

Areas

The possibility of localising the machinery within the construction site is again an opportunity, having a site that is divided into areas within the BIM model opens the opportunity of link the information to a specific space.

The machinery is carrier of its own risks that are not dependant from its application, such risks are for example: mechanical malfunctions, vibrations transmitted to the operator, improper usage and so on. So, whenever the machine joins the work environment it will include a series of risks that need to be considered. Then there are risks that are linked to the presence of people or other machinery, these risks are for example: crash between vehicles, running over pedestrians, breathing of the dust produced. And as late type of risks we have the one induced by the area itself, for example certain part of the site may have the presence of threes, buried plumbing, aerial networks and so on. All these kinds of risks should be evaluated into the PSC but during the construction process there may be times where a more active surveillance may be required in order to prevent accidents.

To integrate the GNSS system with a BIM informative model the machine may be equipped with additional automatic setting. Such settings that can act on:

- Maximum vehicle speed
- Maximum/minimum range of the excavator arm
- Maximum angle of rotation of the turret
- Maximum extension of the arm

Usually, such constraints are manually inserted by the operator, for example for a Caterpillar excavator such technology is call E-fence.

So, the idea is to predefine the obstacles and limitations that the machine operator should observe within a specific area and include them within the database of the areas. So, whenever the machine will enter the target space an automatic set of constraint will be applied to the machine. This kind of solutions involved the producer of the equipment, the developer of the GNSS system and the BIM expert. Again, the key point of the problem is that the machines are designed to serve their purpose of productivity and their integration with the BIM now is a forced process.

Another application of the site areas is the possibility of keep under control in real time the risk present within a specific space. The risks listed into the PSC are linked to works and tools that are also linked to the time that will be used. So, there is the possibility of developing a BIM oriented platform that can show the current risks that are present within the site areas at a given time. Furthermore, since the machinery can be localised in real time and the assigned workers are included within the WBS it is always known the crowding of the spaces, that can be evaluated with a range in percentage from 0 to 100 of how much safe the current situation is. The percentage evaluation can be done by summing the risk present within an area and by evaluating how much severe they are and how much likely is going to happen.
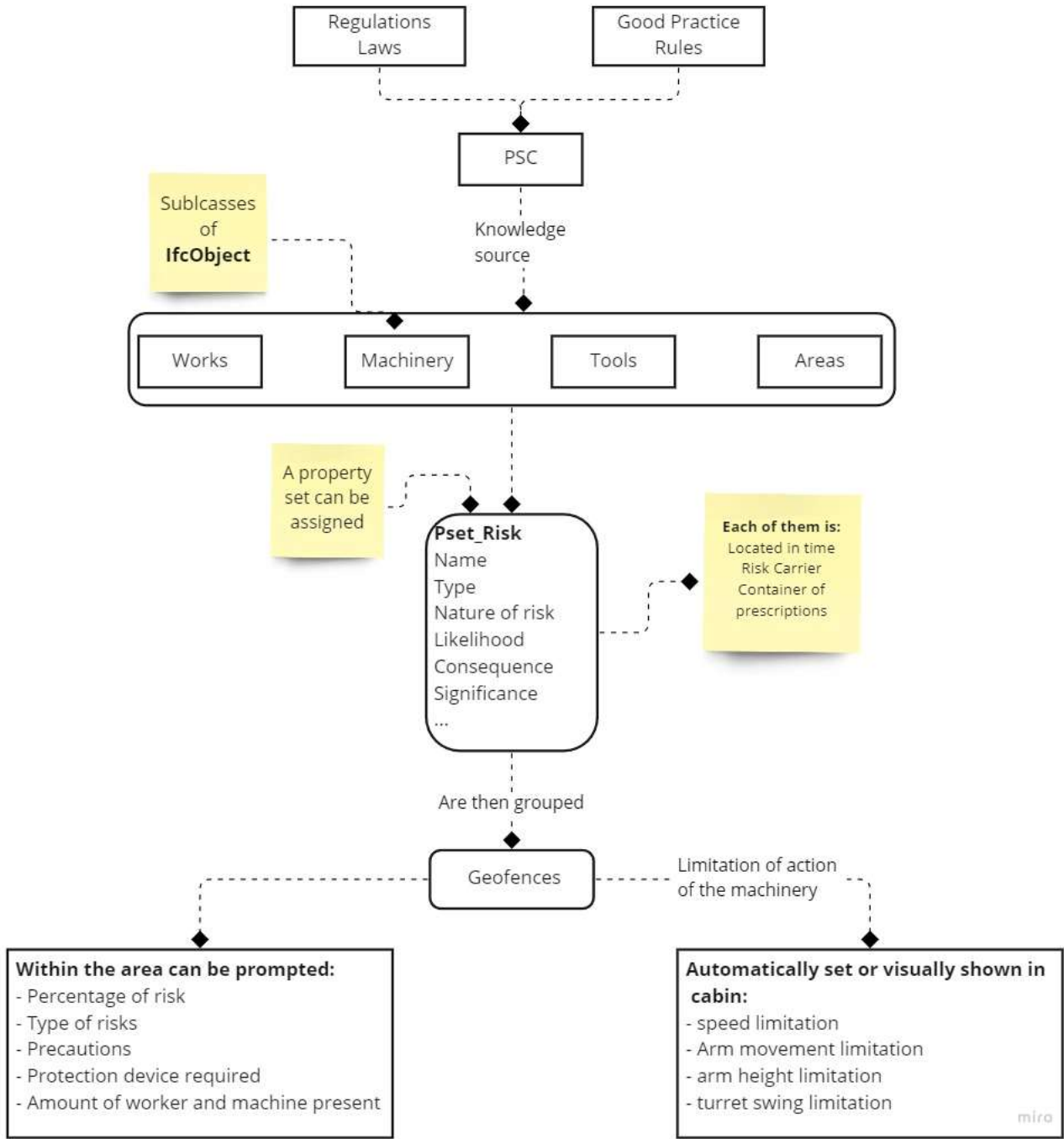
Figure 105 - BIM for safety with geofences

The scheme above is visually presenting what have been explained in words. To clarify, it is briefly described below.

The PSC that contains the safety measures and the risk assessment study with the consequent risks list is drawn up thanks to the regulations, laws and other source of knowledge. The risks that are linked to the objects (Works, Tools, ….) are categorized according to the likelihood and their magnitude. The objects can include all these information thanks to the Pset_Risk that can be applied to all the subclasses of IfcObject. Tools, worker, machinery and workers are then identified within the space

and time according to the WBS and thanks to the deep analysis of the process clash within the PSC. The geofence once again works in the end as carrier of what is happening at a given time within their areas giving then the results and applications that are shown at the end of the graph.

Such approach can be further integrated with the idea of a smart and controlled site, where all the activities and actors are tracked according to position and type of works, a deep study of the possible sensors that can be implemented is given by Aravinda S. Rao et al. [70]. While a strong application of worker real time positioning is given by A. M. Costin et al. [71] which uses RFID and BIM-enabled information to track the location of the worker in real time.

Soil Properties

One of the biggest risks linked to excavation is the failure of the walls of the pit.

According to the Italian Law during excavations works if the workers are meant to enter the hole, the inclination of its side should consider the natural behaviour of the material [40]. So, it should be performed a proper study of the soil and correctly fill the sheet of properties linked to the material. With the version 4.3 of the IFC schema it will be introduced the entity IfcSolidStratum, and at the point 6.5.4 "Property Set" of IfcSharedInfrastructureElement we can identify the two property sets

- Pset_SolidStratuCapacity
- Pset_SolidStratumComposition

Here below described the relationship to describe the Solid Stratum and its possible property sets.
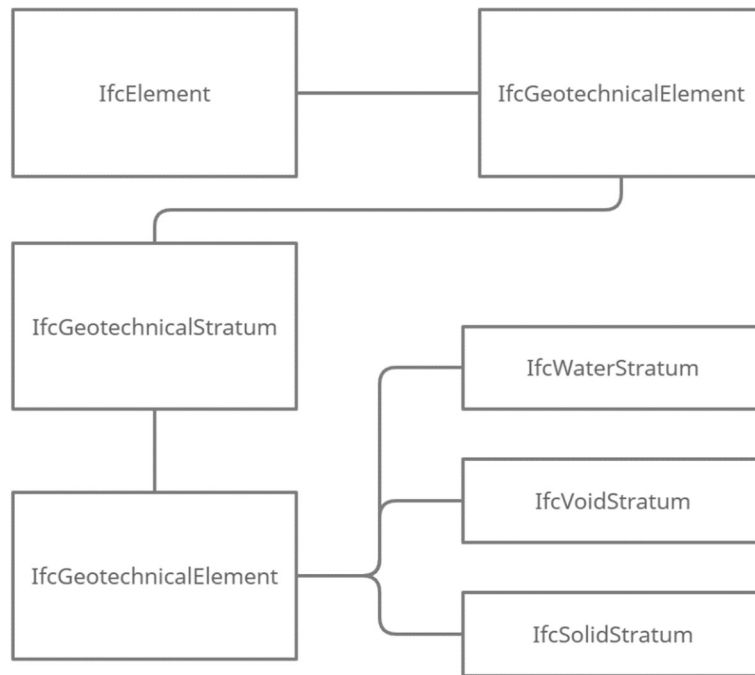
Figure 106 - Definition of IfcSolidStratum using IFC 4.3

Name	Type
AirVolume	P_SINGLEVALUE / IfcVolumeMeasure
BouldersVolume	P_SINGLEVALUE / IfcVolumeMeasure
ClayVolume	P_SINGLEVALUE / IfcVolumeMeasure
CobblesVolume	P_SINGLEVALUE / IfcVolumeMeasure
CompositeFraction	P_SINGLEVALUE / IfcCompositeFraction
ContaminantVolume	P_SINGLEVALUE / IfcVolumeMeasure
FillVolume	P_SINGLEVALUE / IfcVolumeMeasure
GravelVolume	P_SINGLEVALUE / IfcVolumeMeasure
OrganicVolume	P_SINGLEVALUE / IfcVolumeMeasure
RockVolume	P_SINGLEVALUE / IfcVolumeMeasure
SandVolume	P_SINGLEVALUE / IfcVolumeMeasure
SiltVolume	P_SINGLEVALUE / IfcVolumeMeasure
WaterVolume	P_SINGLEVALUE / IfcVolumeMeasure

Name	Type
CohesionBehaviour	P_SINGLEVALUE / IfcPressureMeasure
FrictionAngle	P_SINGLEVALUE / IfcPlaneAngleMeasure
FrictionBehaviour	P_SINGLEVALUE / IfcPressureMeasure
GrainSize	P_SINGLEVALUE / IfcPositiveLengthMeasure
HydraulicConductivity	P_SINGLEVALUE / IfcVelocityMeasure
LoadbearingCapacity	P_SINGLEVALUE / PressureMeasure
NValue	P_SINGLEVALUE / IfcCountMeasure
PermeabilityBehaviour	P_SINGLEVALUE / IfcRatioMeasure
PoisonsRatio	P_SINGLEVALUE / IfcRatioMeasure
PwaveVelocity	P_SINGLEVALUE / IfcVelocityMeasure
Resistivity	P_SINGLEVALUE / IfcElectricResistanceMeasure
SettlementBehaviour	P_SINGLEVALUE / IfcPressureMeasure
SwaveVelocity	P_SINGLEVALUE / IfcVelocityMeasure

Figure 107 - Property sets, SolidStratumComposition (left) and SolidStratumCapacity (right) – [41]

A table that contains the angles of the walls of the pit that guarantee stability of the material without the usage of reinforcement is given below. Also, it is reminded that according to the law, for excavations of trenches deeper than 1.5 m it is forbidden to perform manual excavations [45]. The table will refer to the geometry expressed in the next picture.
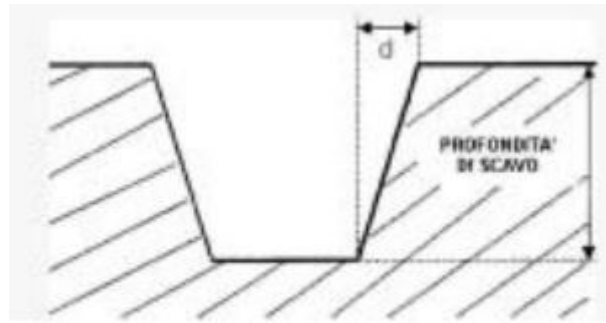
Figure 108 - geometry of the trench to allow its wall stability, [45]

Material	Angle of safety	d (m) for trenches deep 1.5 m	d (m) for trenches deep 2 m
Rocks	90°	0	0
Compact soil	63°	0.8	1.0
Soil with medium consistency	45°	1.5	2
Compacted sand	33°	2.3	3
Loosen sand	26°	3	4

For a correct estimation about the safety of the walls of the excavation site it may be required to implement additional rules within the code checking, that are the estimation of the safety factor FS for a non-cohesive material and a critical height for the cohesive material.

For non-cohesive material, a value of FS higher than 1 means that the excavation site can be considered safe, in absence of significant variation of the boundary conditions. The safety factor is then calculated as follows:

$$FS = tg\Phi/tg\beta$$

Where:

- φ is the friction angle within the material
- β is the inclination of the walls of the pit

For the cohesive materials, the presence of internal forces allows to overcome the friction angle of the material particles and it is possible to create quasi-stable vertical walls (typical for clayey soils).

So, the critical height (H$_C$) of the wall is calculated as follows:

$$H_C = 4c/\gamma_n$$

Where:

- c is the cohesion
- γ_n is the natural density of the terrain

Thanks to the oncoming expansion of the schema most of the results coming from the soil survey will be integrated within the BIM environment, so by setting safety rules and automatic checks it is possible to have some warnings about, as example, the modelled slope of an internal road (or trench wall) made by a certain material. An example of this application is the Revit Plug-in studied and developed by J. Yuan et al. [37], which it will prompt the error message related to a not respected rule on a certain modelled entity.
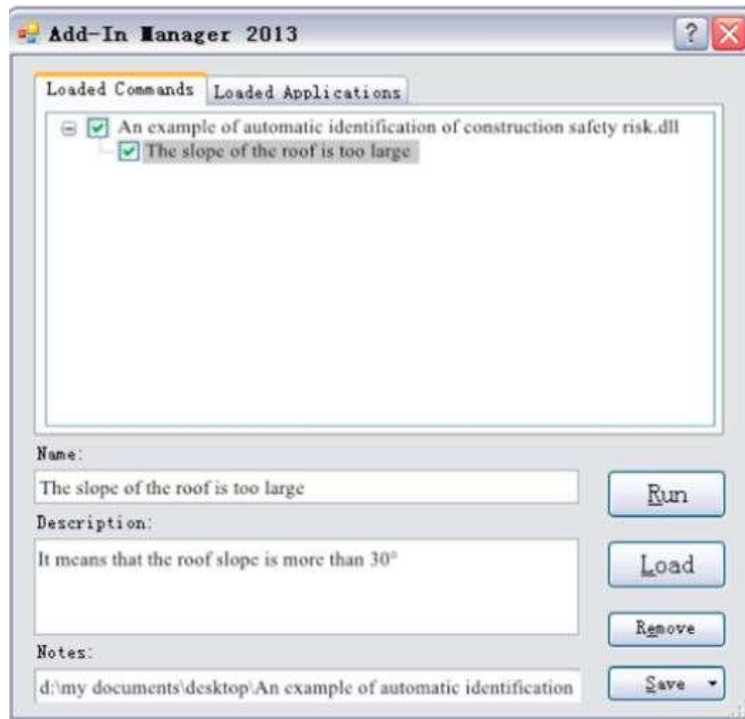
Figure 109 - Prompted error message from the Revit Plugin - [37]

Figure 110 - Visualization of the location linked to the error - [37]

Presence of existing network

It is in the end mentioned the risks that are linked to existing networks.

After the geological study of the site, it is recommended to perform a deep and precise analysis of the possible existing plumbing or tube network and structure underneath the site. Damaging gas tubes brings the risk of explosion or fire spread and the situation becomes severe if is the excavator bucket that cause the damage, the heat coming from the machinery or possible sparkle can be a reason of sudden explosion. Other networks are the water plumbing and the electrical and data networks, if the last are damaged the direct risk for the operator is less but it can cause discomfort for the neighbourhood due to the interruption of a specific service. So, damages to this network generate risk for workers, possible time delay and additional costs. The integration with the GIS system is fundamental to localize these linear structures among the site and the BIM method will be used for information management with a deeper detail.

Among the literature one of the most valuable solutions is given by A. Sharafat et al. [42] that proposed a full approach to identify existing network and integrate such information within the machine guidance system. The approach consists into generating a complete model thanks to a deep surveying campaign by using UAV and GeoRadars. Then the results from both scans are processed and are geo-localised in order to overlap the position of the buried network and the 3D surface model generated by the UAVs. In the following picture is shown a picture taken from the paper that explains the process thanks to a diagram.
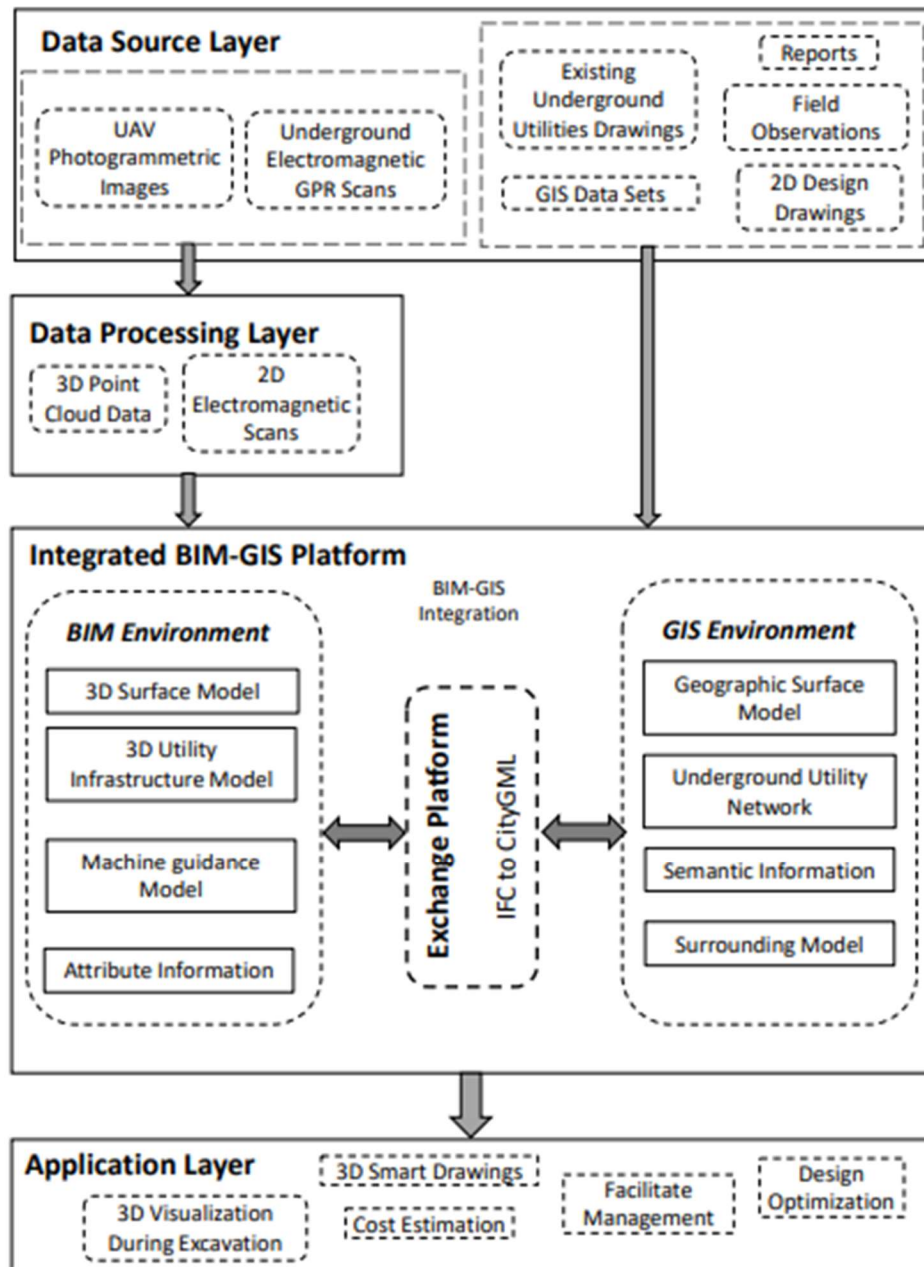
Figure 111 - Approach for a BIM-GIS integration for localisation of buried network - [42]

The resulting informative model is then giving to the engineer the information about positioning and characteristic of the linear element, giving the possibility to plan accurately the excavation and is giving to the machine operator a 3D overview of the buried network.

6 Conclusions

With the Dynamo automatic script is shown that within Revit is possible to merge two different Topographical surfaces by means of their own LandXML file. The mapped surface coming from the excavator that have been exported thanks to a dedicated CAD software (HCE) can be successfully merged with an already modelled surface by including all the points within one single list. The result is the possibility of updating the instance "TopoSurface" without the need of creating a new one. This first attempt of integrating a mapped surface for site updating is showing that the results of the machine guidance, if cleaner and smoother, may be used to reduce the time and costs linked to the surveillance for updating the as built conditions and the quantities linked to the excavation process. The script can be so used for both Revit and Civil3D where it has been seen that the second one can be a better solution thanks to its powerful tool of GIS management. The suggested solution for the BIM integration of the earthwork processes and the machine guidance is mainly orbiting around the concept of dividing the construction site in areas "Geofences" that are the containers of the information linked to the processes that have been executed within their geographic coordinates. The machine while is located within a geofence will label the produced data according to the works that is performing in order to have later an automatic organisation of the exportable results. The study performed over the exportable files shown that such technology is mainly focused in improving the productivity of the machine rather than being integrable within the BIM approach.

The transition of the earthworks toward a full integration of its processes into the BIM interoperable cycle is only at the beginning. This statement can be proven just by searching for existing studies by reading over the producer websites and by the ongoing development of further schema and regulations. What have been proposed within this thesis is to collect part of the knowledge about: the actual technology, the standards and regulations, the future developments and then to experiment some possible solutions that, with further study, may be proven correct or be updated. The explanation and premature usage of the new IFC 4.3 schema brought to the surface a series of possible future applications, proving that the "BIM world" is willing to accept the earthworks processes within its cycle.

Then, the usage of the machine guidance, a technology that is on the market since years until now, is still not taken too much into consideration, especially in Italy. But, from the results of the analysis performed it have been proven that the applications may be several and that such technology is lacking a better application technique. So, the usage of the machine guidance on an excavator as a survey robot is still a theory that can be proven trough some further site test. The main requirements that can

help the development of the automatic survey are a change in technique, a wider knowledge of the machine operator, a bigger choice of mapping conditions and an improvement of the machine side software.

It is already proven that the machine guidance itself can improve the productivity of the dig, levelling, grading and compacting operations. But the combination of such technology with the BIM approach may lead to some real improvement of the whole site and earthwork operations, that are more than only "excavations", the studied approach aims to improve the safety of the workers, to improve the data collection during the construction phase, to help filling the documents that need to be produced periodically (e.g., the book of measures). All these benefits are possible if the earthwork processes are correctly integrated within the other disciplines and can be boosted by the usage of a technology that is following the most important aspect of the machinery in real time, their productivity.

For further studies it is suggested to test different types of mapping procedure and to try to develop platforms that can handle the earthwork information once they have been translated into the IFC schema.

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8 Table of Figures

Annex A – IFC entities mentioned

Name	IFC 4	IFC 4.3
IfcRoot	X	
IfcObjectDefinition	X	
IfcProject	X	
IfcGeometricRepresentationContext	X	
IfcAxisPlacement3D	X	
IfcSite	X	
IfcGeographicElement	X	
IfcProductDefintionShape	X	
IfcShapeRepresentation	X	
IfcTriangulatedirregularNetwork		X
IfcPropertyDefintion	X	
IfcRelationship	X	
IfcObject	X	
IfcProduct	X	
IfcElement	X	
IfcBuiltElement		X
IfcEarthworksElement		X
IfcEarthworksFill		X
IfcCourse		X
IfcFeatureElement	X	
ifcFeatureElementSubtraction	X	
IfcEarthworksCut		X
IfcGeothecnicalStratum		X
IfcSolidStratum		X
IfcVoidStratum		X
IfcWaterStratum		X
IfcBorehole		X
IfcGeotecnicalElement		X
IfcGeotecnicalAssembly		X
IfcGeomodel		X
IfcGeoslice		X
IfcActor	X	
IfcProcess	X	
IfcResource	X	
ifcGroup	X	
IfcProduct	X	

Name	IFC 4	IFC 4.3
IfcPropertySet	X	
IfcClassifcationReference	X	
IfcClassification	X	
IfcSharedInfrastractureElement		X
IfcPavement		X
IfcVehicle		X
IfcQuantitySet	X	
IfcLocalPlacement	X	

The table above is collecting all the main entieties that have been mentioned within this paper and it is also declare whether they are from the current IFC schema or the one that has being developed. Such table wants to contribute to a better collection and definition of what should be considered while creating a file to be exported that contains Earthworks informations.