Life Cycle Cost (LCC) and Sustainability. Proposal of an IFC Structure to Implement LCC During the Design Stage of Buildings

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Abstract. The role, the economic relevance and the impacts of the construction sector in the world demand, in today's society, increasing requirements in terms of sustainability and efficiency. According to ISO 15686, the LCC (Life Cycle Cost) methodology is a useful technique that allows the evaluation of comparative costs during a specific period of time, taking into account all relevant economic factors, both in terms of initial capital costs and future operating costs. However, the integration of this powerful methodology into building design tools is still poor, limiting the ability of projects to optimize the costs of buildings during their life cycle.

The emergence of IFC (Industry Foundation Classes) technology in the field of architecture, engineering and construction, helped the exchange of information at the design, construction, operation and maintenance stage of a project to be shared independently of the design tools that currently exist, based on a BIM (Building Information Modeling) model that can contain relevant data related to the project/built asset [25]. According to buildingSMART, IFC are the industry's core classes (IfcDoor, IfcWindow, IfcBeam, etc.) that form the basis for globally recognized data exchange and interoperability.

Therefore, this document presents a structured proposal for LCC to implement at IFC. The proposed structure has been developed based on the ISO 15686 standard, which contains the main costs according to the construction phases. With this proposal, it is expected to encourage the implementation of LCC during the design phase of the project in BIM, to achieve more economically efficient buildings.

Keywords: Life Cycle Cost (LCC) · IFC · Building data structure · ISO 15686 · Cost optimization · Economic building sustainability · Building Information Modeling (BIM) · Building design tools

1 Introduction

Making the best decisions before starting a construction project has become a factor in determining the success or failure of such projects because buildings have become larger

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and more complex. Particularly in the life cycle of a construction project, the planning and design phases have an important weight (Kaplan and Norton 2005), in these stages important decisions are made such as the outline of a building and the selection of design alternatives. Furthermore, the preliminary estimate in the initial design phase determines not only the viability of the project but also the total cost of the project (Azman, Abdul-Samad and Ismail).

Decision making in the planning, schematic design, final design phases affects construction costs as well as costs incurred for the maintenance and dismantling of building structures. Therefore, decisions must be made with the life cycle cost (LCC) in mind.

To support decision-making regarding the key elements of a construction project and the selection of design alternatives in the initial design phase of the project, the scope of this study was limited to structuring IFC, including ISO 15686, the LCC methodology in the initial design phase.

This study proposes an IFC import and export method from a BIM model. The criterion was structured and linked to the BIM model, to include LCC data in accordance with ISO 15686. The precision of the prototype was to verify the information on a BIMCollab display applied to a steel construction system, the validity of the method of supporting the shot of project planning and design decisions [30].

2 Life Cycle Cost (LCC) Methodology

2.1 LCC Definition

Life Cycle Cost (LCC) concept was implemented in a structured way from the 70s, specifically the United States Department of Defense in the area of military aviation [1].

However, most of the methodologies developed by the defense department were oriented to purchasing and logistics processes and exclude the design and production phase. Once the need to apply the LCC methodology in the production design, planning and control processes was recognized, the US National Science Foundation sponsored a conference in 1984. In this conference the research areas were identified and prioritized, receiving the qualifications Highest prioritization areas: economic evaluation in the design phase, life cycle analysis [2].

LCC is defined by ISO 15686 [3] as a “valuable technique that is used for predicting and assessing the cost performance of constructed assets”. The LCC also “allows consistent comparison to be performed between alternatives with different cash flows, Fig. 1 and different time frames” [3].

2.2 LCC and LCA

The life cycle assessment (LCA) is an analysis of the possible environmental impacts both in the use of resources and in the consequences of emissions produced during the life cycle of a product or production system.

LCC moves away from the concept of inventory of interpretation of inputs and losses of different elements of the system, directing its interest to predict and evaluate the performance of the costs of the built goods. Life cycle costing is a form of analysis to determine if a project meets customer performance requirements [26].

Fig. 1. Cost flow, Sustainability workshop, México, 2018

Therefore, the LCC is not an exclusively environmental measurement tool, although it incorporates the concept of "life cycle". It should be remembered that sustainability is more than ecology and, therefore, the LCC can be considered a useful instrument for evaluating the costs that are included in a sustainable project.

2.3 LCC and Risk

The LCC has become a main tool in decision-making. [4], projects are not only related to financial concepts, but also to the environmental impact they can produce.

Various techniques are needed to assess risk management to predict the future. This process is determined by parameters or variables such as the discount rate and the Net Present Value (NPV) related to a sensitivity and probability analysis. Two particular techniques related to resource optimization in the LCC construction industry were considered [5]. On the one hand, the discount rate used to convert future values to present values and vice versa and, on the other hand, the NPV is the standard criterion for deciding whether an option can be justified by economic principles.

2.4 LCC and Industry Construction Costs

Woodward [6], not only exposes the LCC methodology, but also identifies the costs and benefits based on the goals established by the Royal Institute, identifying the following elements of the LCC: (1) Frontal capital costs; (2) The life of the asset; (3) The discount rate; (4) operation and maintenance costs; (5) Disposal costs; (6) Information and comments and (6) Analysis of uncertainty and sensitivity.

When exploring the most significant variables that have had to attack the construction of the LCC industry, Sterner proposes to include the initial costs (cost of lot, design, construction), operating costs (energy costs, cleaning), maintenance costs (costs annual, substitute costs, contingencies) and recovery costs are also related to previous costs, the discount rate that varies in a proposed sensitivity analysis and is part of the uncertainty exposed by the LCC [37].

It is important to distinguish between the LCC (life cycle cost) and the WLC (cost of a lifetime) in which ISO 15686-5 [3] (reference in LCC) establishes that the LCC study includes: construction, operation, maintenance and demolition, Fig. 2.

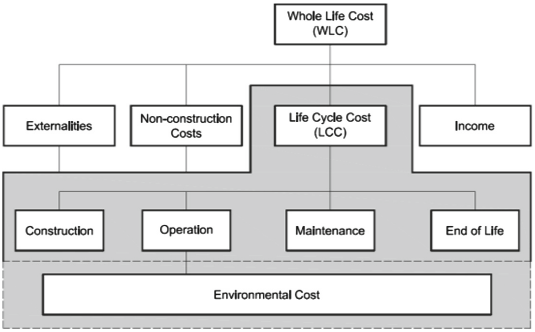

Fig. 2. WLC and LCC elements

2.5 LCC Utility

In 2007, the European Union (EU) published a report whose objective is to propose a common methodology for the implementation of LCC in EU countries [7] This report was the basis for ISO 15686-5 [3] this report It also intends to connect LCC with LCA. Analysis and application could be directed to evaluating a project based on comprehensive and competitive decision making. On this basis, the plan proposes a series of approaches that are described below:

The use of LCC and stroke as two of the criteria in evaluating a single investment option (for example, the decision to build an asset), where other criteria evaluation could include functionality, aesthetics, construction speed, future investment returns, etc.

The use of LCC and LCA as two of the criteria in the assessment of several alternative investment options (whether constructed entire specific goods or components, materials or assemblies within)

The use of LCC to provide a financial/economic evaluation of the impacts of sustainability that have a monetary value widely accepted and easily calculated;

The use of LCC to provide a financial/economic evaluation of the options identified in an LCA evaluation;

The use of LCC as a means of identifying options with good environmental performance and then carry out an LCC analysis in these options only;

The use of LCC to select cost-effective options; to make a final decision in the light of a process of LCA conducted only for those options.

2.6 LCC and Green Buildings

We call green buildings those sustainable constructions that use natural materials, that reduce and optimize their energy and water consumption as much as possible and that integrate into their environment, whether natural or urban, causing the least possible environmental impact [3].

There are different institutions, organizations (US Green Building Council, USGBC) and even independent entities that are responsible for promoting sustainable architecture and construction through the implementation of certification processes that will be in charge of evaluating the degree of sustainability of the buildings. With the voluntary certifications (LEED, EDGE, PEER, WELL, SITES, GRESB, BREEAM), Fig. 3, it is intended to guarantee that green buildings meet a minimum standard of conditions established by each certification body.

Fig. 3. LEED in the world, Sustainability workshop, México, 2018

Some of the benefits of having green buildings are: Reduction of energy uses, reduction of water use, and the correct management of waste uses [8].

The purpose of LCC in green buildings is to review initial costs, long-term costs, and possible cost changes, during the decision-making or evaluation process. It also usually includes contributions from other assessments (environmental assessment, design, safety assessment, functionality assessment, compliance assessment) [3].

Current studies based on LCC show the existence of different approaches and contexts that manage and establish an initial point of view for this research [8–14]. LCC-based studies show the growing interest of green buildings against conventional buildings [8].

As can be seen in the following image, carrying out a green project against a conventional project can have an increase of 20–30% of the initial cost, this is due to the use of new technologies to reduce energy costs. The considered range of return on investment in the construction of a green building, (ROI) is between 4–6 years. There are benefits in reducing operational costs, this is due to the economic savings that a green building brings (Fig. 4).

Fuente: Green Building Canada

Fig. 4. Payback, Sustainability workshop, EU, 2018

3 The Industry Foundation Classes (IFC)

The following study wants to publicize the advantages and IFC structure, to relate it to LCC, the application will be made in a case study and verify if there is no data loss during the process.

3.1 IFC and Building Information Modelling (BIM)

IFC stands for Industry Foundation Classes, it is a common standard for data exchange in the construction industry and information is shared regardless of the software application used. IFC is an object-oriented file format, which can be used in BIM-based projects [15].

BIM allows that data used throughout the lifecycle of a building remain stored and reused for multiple purposes. According to building SMART [15], the IFC format is the main tool for the implementation of Open BIM, "which represents a universal method for collaboration in the design and construction of buildings based on standard and open workflows." Once exported, the IFC model contains not only the geometry of the building and the building data, but also all information contained in the native BIM files. When native data are exported to an IFC file, data can be transferred between applications. This operation is free and is well documented and allows the use by hundreds of other tools and BIM applications.

In north of Europe, countries such as Denmark have promoted its use for construction projects with public aid. In Finland, the facility management company owned by the state, Senate Properties, now requests the use of software compatible with IFC and BIM in all its projects. In addition, the Norwegian government is mandatory to use BIM IFC projects. In industry, many municipalities, private clients and contractors have already integrated this format in their business.

IFC has its strengths and weaknesses, in accordance with ISO 16739-1 [17] The process involves a loss of data and intelligence of the object. One of the advantages is having an open-format virtual building, which allows contractors to take the first approach to design, Fig. 5.

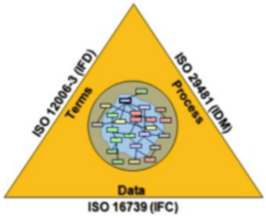

Fig. 5. ISO standards. (Source: BuildingSMART international)

Today, the IFC format in building projects is used for visualization and detection of crossings. During the first phase of a project, the design team can merge or reference the discipline of the models independently of the original application using an IFC file, Fig. 6. They are also used to import data from one application to another [16].

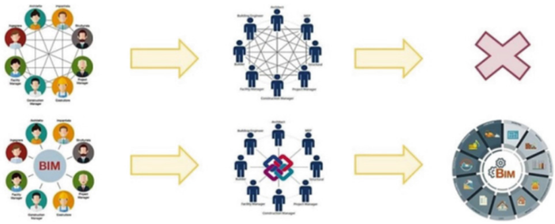

Fig. 6. Interoperability and open system. (Source: BuildingSMART international)

3.2 IFC Versions

Figure 7 shows the evolution of the IFC way of life, which received several updates and improvements, reflected in different release versions. The most important have been two of them: (1) the IFC2x version released in October 2000 and updated to IFC2x3-TC1 released in July 2007, and (2) the IFC 4 version, released in March 2013 after 6 years of improvements (approximately 1200 improvements and corrections) and documentation.

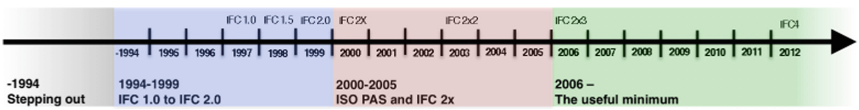

Fig. 7. IFC timeline (Source: BuildingSMART international) [15]

3.3 Structure IFC

The IFC architecture bases its own structure on:

- Semantics
- Relationships
- Properties

The elements are intended to describe the components of buildings, such as facilities, spaces, areas, furniture, structural elements (pillars, beams, walls, floors, etc.), including the specific properties of each object. Thanks to this subdivision it is possible to associate, to each object, specific greatness such as:

- Shape
- Costs
- Need for maintenance
- Position
- Energy provision
- Connection with other objects
- Security
- Physical and mechanical characteristics

All of this data is generally encoded in one of the three available formats:

- .ifc: predefined file format based on the ISO-STEP standard
- .ifcxml: coding based on XML language
- .ifczip: compressed file of one of these formats, which may also contain attached material such as PDF or images.

It is important to know the type of files when exporting the information, so that the coloration between the figures involved is correct, Fig. 8.

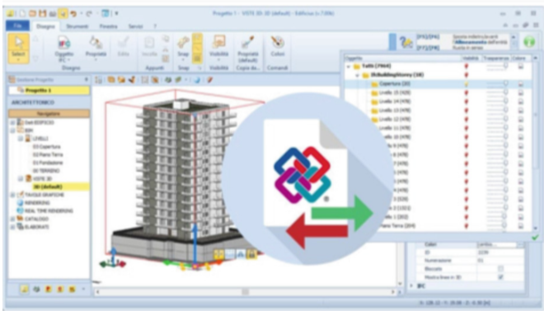

Fig. 8. Open BIM (Source: BuildingSMART international)

Model View Definition (MVD) represents subsets of the IFC schema defined by buildingSMART International and groups together certain information useful for specific workflows or uses.

These views are very useful since they simplify the data exchange process and avoid sharing useless or redundant information, following standardized procedures.

The following image shows a schematic that gives an idea of the IFC schema and how a specific MVD, Fig. 9, can simplify it based on useful information for a specific purpose.

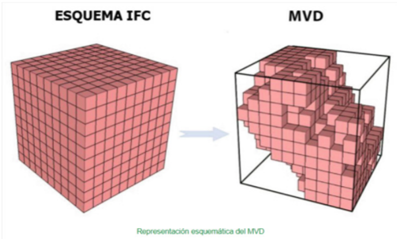

Fig. 9. Schematic representation MVD (Source: BuildingSMART international)

In conclusion, considering the image above, we can understand the MVD as a filtered view that collects part (or all) of the information regarding the entire IFC schema.

Imagine then, the different MVDs applied to the federated model, obtaining:

- Structural model
- Architectural model
- MEP model

In this way we can include costs by disciplines in the MVD, which helps us to carry out separate analyzes, understanding that they are part of a construction.

3.4 New Trends in IFC

IFC is a data model used to characterize both the building information and geometry along the life cycle of the building. It has become an open ISO standard supported by the industry and promoted by the global non-profit buildingSMART [15], which has created a professional certification program. The first part of the program is called individual rating and aims to standardize and promote the content openBIMtraining, support and accredit training organizations and evaluate and certify individuals, Fig. 10.

According to [18] currently, project planning and execution phases of construction the main uses are compatible IFC. In addition, many designers use this exchange format when working with different software, and architects use solutions such as AECOsim or ArchiCADand engineers using Revitor DDS-Cad. Everyone has their native extensions, but give this option and flexibility to the workflow. The IFC provides geometric compatibility in a common environment and export for analysis in other software. However, one

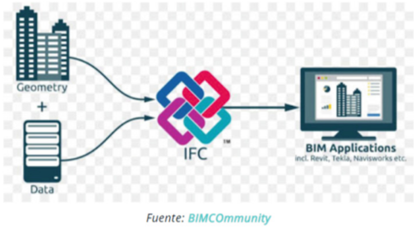

Fig. 10. Exchange of information (Source: Linkedin)

major barrier is that the export of the information in the models is not always correctly translated. For example, IFC Export from the modeling software such as Revit to another software such as ArchiCAD can cause data loss. This lack of interoperability is evidence by [19] as "BIM market coordination problem".

If we follow the BIM methodology, it becomes clear that the IFC can be useful if we know its limitations. To achieve it, user must perform tests to ensure that the IFC format can be used in each specific case [31]. When user start working with the IFC data model, it is warned that the available examples were slight variations each other. For example, the same element in a project had a different structure than in another. At that time seemed a problem of incorrect modeling, but later clarified that the difference was due to the version of IFC in which were developed some models and others (Fig. 11).

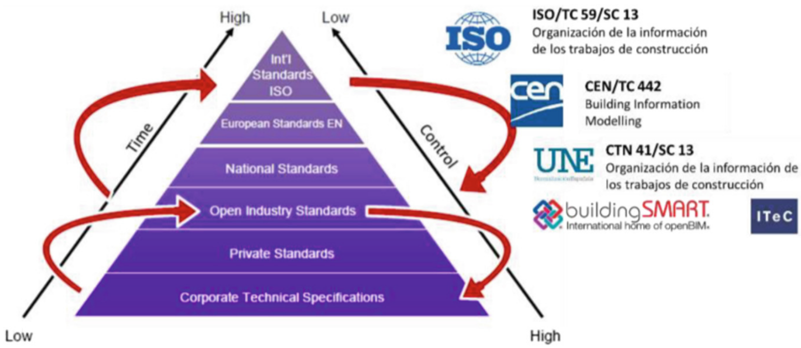

Fig. 11. ISO (Source: Linkedin) IFC proposed structure applied to LCC

3.5 Current Structure of the IFC

The IFC format is based on a class hierarchy as a tree, starting east of a root node which inherit all other entities directly or indirectly [20]. This root node is called IfcRoot and is a superclass of all other entities. Element unfolds tree hierarchy, beginning by the differentiation of the three main types of entities, IFC includes: (1) object definition, (2) definition of properties and (3) relationships. Each of these nodes acts as abstract definitions of the elements. With this, at every level that the hierarchy can be moved down, new attributes can be added inherited from the parent. Thus, when the leaf nodes are obtained, that is, the products themselves, the full definition is achieved [20].

Figure 12, shows the inheritance tree of a object in IFC. It can be seen, how large the number of levels from the root node to the element. In each of these levels by passing the definition until the product it brings something to it. The IfcRoot inherits the 4 graphic elements of any product: (1) the single global id, (2) reference the owner who created the item, (3) the name and (4) the description. The attributes that make up an entity can be of two types: direct or inverse. Direct attributes contain information stored directly on the instance of that entity, while the reverse (which usually are relations) means that no other entity can have as an attribute to the extinguisher itself [34]. This structure is common to all IFC entities, although the attributes and the relationships can vary. Besides working on different platforms and specific modelers, it is possible to use BIM models in IFC format for making measurements and budgets. Since this is an exportable and importable format by BIM software modeling, calculation or management because it uses a format standard for information exchange, open and internationally accepted code, we will have the freedom to work with software not tied to the platform native creative model for budgeting.

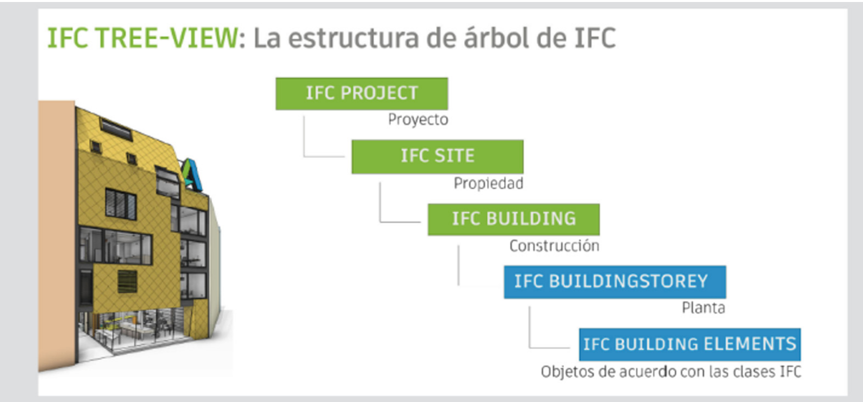

Fig. 12. IFC structure (Source: Revit IFC manual [20])

According to [21] an IFC model as in a native pattern, is a graphical database, that can be export from different software modeling, and can be read in the same modeling software. This language IFC, the same way as native models, includes over 600 "classes" the different elements of the building works and civil works. In the IFC models it is defined geometry, materials, properties and relations between structural elements. Due to their complexity not all attributes of the elements of native models can be found in the IFC models, but those for making measurements and budgets are: (1) class or name, (2) material, (3) quantities and (4) phases. Figure 13 shows an EXPRESS-G diagram ofIFC model structure.

An important point in connection with the writing and reading of model elements IFC, is the GUID (Globally Unique Identifier), which uniquely identifies that element, thus making measurements with IFC models can relate each GUID item with one or several

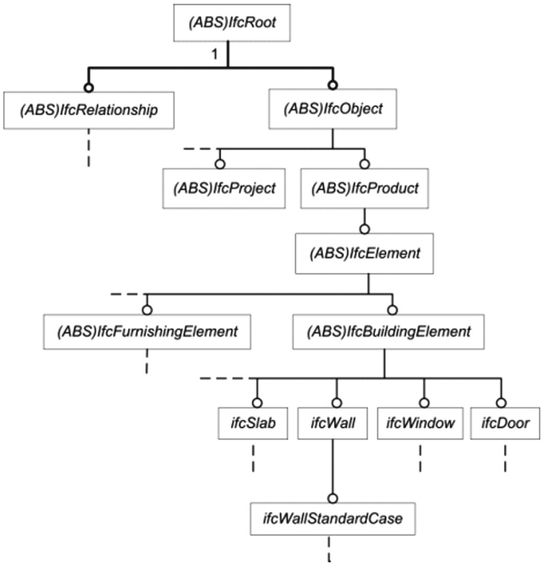

Fig. 13. EXPRESS-G diagram of IFC model structure (Source: [22])

budget items. One of the aims of BIM model is the quantities takeoff, measurements and economic control of the project.

In BIM, workflows should be a two-way communication between modeler and responsible measures to resolve such situations as just discussed. The solution adopted in this case is advisable to pass the modeling standards, so that in the future the teams work with that standard adequately the false ceiling in the case of double heights modeled, and the head of measurements has the security that can extract data model with correct placement heights of ceilings, i.e. the data contained in any model are reliable for the use in flow BIM.

Therefore, both BIM standards of a company, as in the BEP, where staying as living documents that are constantly improving. It is unfeasible to make a BIM sit standard for modeling, and think that it will solve all cases and doubts that may arise during modeling [32].

Moreover, BIM Project management recognize several BIM dimensions, related to the working process in building design. The 2D (drawings) includes the traditional plans and drawings (lines, images, renders) [23]. The 3D (model) allows allow the building to be toured [23]. The 4D (time) enables to plan the construction process and the 5D (cost) includes the cost estimation and measurements [23]. Even though there still no consensus to define the sixth dimension, [24] argue that it should be sustainability, due to the relevance of the subject.

3.6 IFC and Measurements and Budget of the Construction Project

As in a conventional process measurement, every part of the project will be measured by specialists in each discipline, i.e. the structure calculator provides measurement and budget structure, the facilities, the MEP, etc, or could be only one responsible for measuring and budget. In any case, the profile measurements responsible for budget will have a range of skills in order to achieve the highest performance measurements extraction from the models. The list of requirements and budget measurements responsible for a BIM process are: (1) professional experience on construction project in the relevant discipline; (2) knowledge of the details and construction processes of the work units and (3) the ability to know the designer to consult on the different elements composing a construction detail, system or assembly [27].

To measure the building, and to know to build it, it is sufficient management interface BIM modelers and IFC viewers, and also: (1) to obtain any necessary to correctly display the unit measured view; (2) to get within the model, the necessary tables, including the tables parameters or attributes to order measurements (level, type, class or subclass, material) including in these tables, an organization, segregation parameters, attributes, types, classes or subclasses, as well as calculating the total and partial generated according sub tables; (3) to create parameters or attributes within tables calculated for measurements, e.g.: multiply the section of a profile length to obtain the volume of material; (4) to create parameters or attributes in the model in order to complete the definition, graphic categories of model elements. eg: parameters or reference attributes hinges and hinges number of types of doors, without having to model the hinges to count them; (5) to export tables to Excel; (6) to hand specific measurement software with BIM modelers and (7) measurements in BEP and in the process map.

3.7 Measurements in BEP (BIM Execution Plan) and in the Process Map

Like the other project deliverables (plans, reports, specifications, calculations, etc.), the budget will be included as a task in the BEP. In the information flow generation BIM measurements and the budget will develop [36]:

- Input data, i.e., the model with the agreed standards for that model serves to measurements, which corresponds to each phase, and date of receipt, and perhaps other document that could define the project as memories of quality or property requirements.
- Output data, which is the budget itself as document as a spreadsheet, BC3 or format that has been stipulated.
- Responsible extraction of measurements and preparation of the budget and a delivery date or publication.
- A review milestone in each phase, through coordination meetings or checkups.

The above points shall appear in the BEP and/or process map, so that all participants in the process have no doubt the "what", "when", "where" and "how" in the flow BIM. As now, it happens with CAD, measurement may have a unique responsibility. It is often the case that different disciplines (installations, structure, safety and health) do their part of the budget, so each budget in the BEP appears such as a separate task. In that case it will always be necessary responsible for receiving all partial budgets and assemble a single budget, and sheet summary of this, for the "budget of material execution," the "contract budget" and "tender budget".

3.8 Structure of Costs to Be Considered in IFC

According to LCC ISO 15686-5 standard [3], the classification of costs can bethe following:

- **Pre-construction costs A0.** Though the theoretical "stages" in which the design process can be divided, construction phase created such as a "strategic definition" where customer is advisable to set the scope of the project, by answering questions such as, the size of the project, the period within which must be operational, the core project requirements and the work teams needed to be developed. This will mark an initial rough idea of the total cost of the project. At this stage, it is also advisable to identify risks, and one of the biggest risks is the gap budget, therefore, factors such as proper evaluation and weighting of the size of the project, deadlines and requirements in the form of qualities and performance of the building will be vital to mitigate this risk. It is also advisable to estimate investment costs.
- **Construction Stage A4–A5.** LCC analysis should consider the costs which are included in the construction phase of the life cycle. Costs should include design and construction, even infrastructure [29].
- **Use Stages B1–B8.** LCC analysis should consider the costs which are included in the use phase of the life cycle. To include operation and maintenance costs of a building. Most of the investment in a real estate asset is not performed during the design phase and construction, in fact, these two concepts usually involve about 30% of the total investment. Most of the investment occurs in operation and maintenance tasks in the building. That is, energy, cleaning, replenishments, security, maintenance and management. This is the building phase where IFC management can produce major savings for the costumer. That is why public and private properties arise not only BIM methodology applied to new projects, but existing buildings, raising the current state models thereof.
- **End of Life stage C1–C5.** LCC analysis must indicate the expenses including the final phase of life (Fig. 14).

A0	A1-A3			A4-A5		B1-B8						C1-C5					Optional supplementary information beyond the system boundary
PRECONS-TRUCTION	PRODUCTION STAGE			CONSTRUC-TION STAGE		USE STAGE						END OF LIFE STAGE					
Land and associated fees / advice	Raw material supply	Transport and all upstream processes from cradle to gate	Manufacturing of products	Transportation to the site	Construction of the civil engineering works	Use	Maintenance	Repair	Replacement	Refurbishment	Use of energy resources, use of material resources, use of water and waste management from the operation of the civil engineering works	Deconstruction / Demolition	Transport to waste processing or disposal	Waste processing	Disposal of waste	Re-landscaping	Potential net benefits from reuse, recycling and/or energy recovery, beyond the system boundary
				Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario	Scenario
A0	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6-B8	C1	C2	C3	C4	C5	D

Fig. 14. ISO 15686 (Source: [3])

IFC creates an accurate inventory of the elements that make up the real estate asset (spaces, facilities, construction elements) in a single database that is the model, the parameters or attributes and metadata that allow calculating the cost of Operation & Maintenance, producing each of the assets, so that these data can be compiled, sorted and transmitted, and quickly analyzed. One of the advantages of using IFC is that the models are unique and centralized repository of all information of the building. With an updated BIM model building, this analysis is performed accurately and quickly, with the ability to transmit information to conventional formats such as spreadsheets or PDF.

3.9 Phases Considered in the IFC Proposed Structure

The phases that have been established in the Implementation Plan developed by BIM Manager for budgeting are:

- Phase 1: Budgeting BIM PBL. Starting from the PBL budget provided by the customer to make a BIM budget for the work to be executed, for it will need to modify some chapters and work units of the original budget, as well as adding new units; due to the expansion of PBL requested by the customer, this new budget will be the budget of the awarded project (hereinafter PA).
- Phase 2: Getting 3D BIM model. Cost discipline primarily part of 3D BIM model developed by the Discipline Corridor. This model contains the BIM objects that make up the linear infrastructure to be constructed. Furthermore, the 3D BIM model works and works existing passage cross drainage along the corridor, is obtained by this cost discipline.
- Phase 3: Getting 5D BIM model. From 3D BIM model will proceed to their interconnection with a tool Budget and measurements in order to obtain a model 5D BIM. For Budget and measurement tools, existing options will be studied to locate the most feasible to implement in a company.
- Phase 4: Initiation of monitoring the work with the 5D Model. It aims to study the process of monitoring work through BIM methodology, identifying work units executed in the first months of work and getting the measurements and proposed work certification.

4 Methodology

The methodology carried out aims to develop a life cycle cost integration model, based on the analysis of ISO-15686_5-Buildings and constructed assets_Service_ life planning_Part 5 Cost of the life cycle, within IFC. Figure 15 indicates the link between IFC and the costs to be considered in a project.

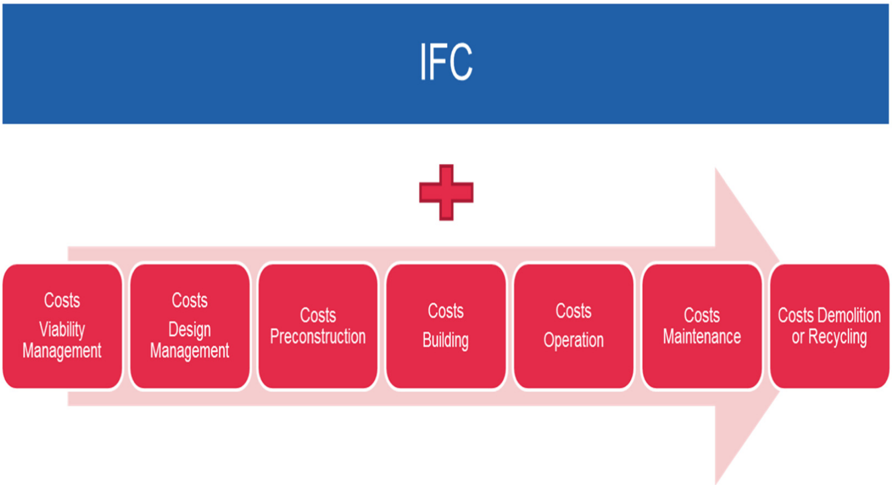

Fig. 15. Integration Proposal, IFC and building costs. Own elaboration (2019).

For this, it will be necessary to carry out a cost analysis according to the life cycle of a study typology. The selected study typology will be a residential building, as it is the most developed typology for a new construction, in Andalusia, Spain (according to data from the INE, 2018). Figure 16, shows how the life cycle costs of a home can be implemented in a BIM model. For this, a breakdown of information that influences a project was carried out and the costs that affect each one were successful, based on the ISO-15686 standard

Model-Level of Detail (Lod)	1	2	2	3		4	
Information shapers	Architecture	Architecture	Architecture	Installations		Architecture	
		Structure	Structure			Structure	
		MEP	MEP			MEP	
			Specialist (Landscaping, Lighting, Etc)				
Information Users	Promotor	Manufacturers	Promotor	Promotor		Promotor	
	Real estate	Products	Real estate	Real estate		Real estate	
	Researchers	Contractors	Researchers	Researchers		Researchers	
	Administration		Contractors	Contractors		Contractors	
			Administration	Users		Users	
				Administration		Administration	
				Facility Manager		Facility Manager	
BIM model		 BIM OBJECT					
ISO 15686 LCC	A0 Preconstruction	A1 Product Stage	A5 Construction of the civil engineering works	B1 Use	B2 Maintenance	C1 Demolitions	C3 Recycling
Cost	Net present value, TIR	Cost of materials	Design Costs (Professional Fees)	Electricity	Structure	Demolition	
	Indirect (Land, permits, facultative address)		Work execution cost	Water		Waste Collection	
	Income (Sales)			Gas		Reuse / Recycling	

Fig. 16. Proposal for life cycle cost analysis, BIM model, IFC. Original preparation (2020)

IFC files create a construction model based on a predefined structure that constructs the model in a logical way. When saved, the IFC file format sorts the units hierarchically according to their type, this way we can include; project data, costs (project, construction, use, maintenance, demolition, waste) as shown in the following Fig. 17.

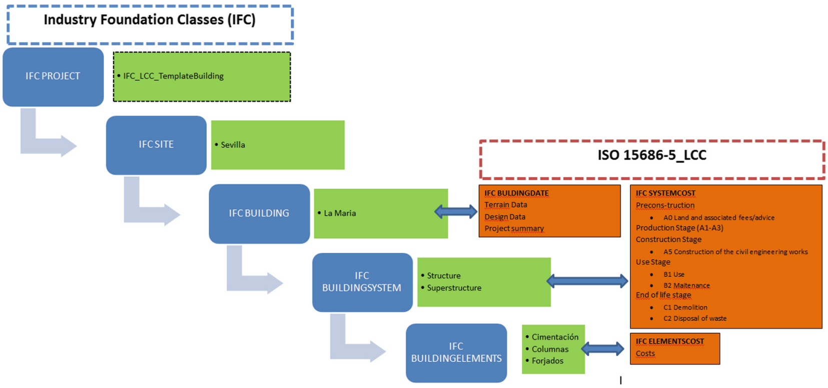

Fig. 17. Proposal for life cycle cost analysis, BIM model, IFC. Original preparation (2020)

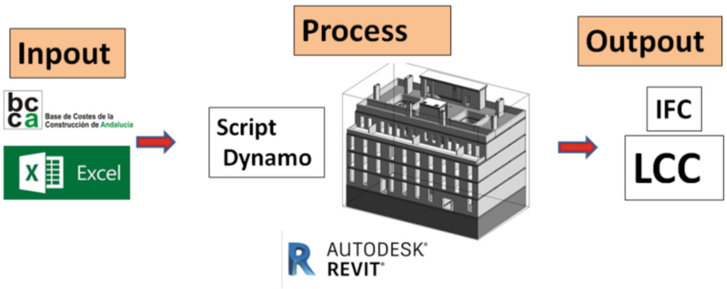

Fig. 18. Model proposal. Original preparation (2019)

For the IFC integration of the LCC methodology, a methodological proposal is described, for its instrumental development, as can be seen in the Fig. 18.

It basically consists of the export of IFC tables with cost information, which is intended to allow the exchange of an information model without loss or distortion of data or information. With this information, a script can be proposed in Dynamo, which combines the information from the BCCA cost model to include it in a BIM model.

– First stage: It is to import the tables with the necessary costs to the BIM model.
– Second stage: The script where the IFC and the database will interact is activated.
– Third stage: An IFC file is exported from the BIM model, with LCC data

Using IFC formats allows the transfer of all the information contained in the same model, in addition to coordinating the different models (Architecture, Structure, Installations).

In this proposal, one of the problems that exist; We have prices that are not in the cost base (such as the costs of maintenance and operation of the building, as well as income) which must be calculated according to the recommendations of ISO 15686_5.

5 Application Case Study

Justification of the Choice

For the LCC analysis, a 3D model made in Revit has been selected, within the ID i project, "Development of a Unified Tool for the Quantification and Reduction of the Environmental, Social and Economic Impact of the Life Cycle of Buildings on BIM Platforms" (Reference BIA2017-84830-R), 2017 State Plan.

It is the steel structure of a multi-family house in Seville, Spain (Fig. 19).

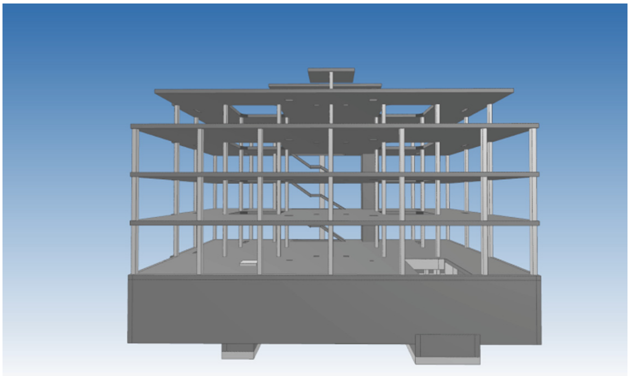

Fig. 19. Model BIM. Reference BIA2017-84830-R (2020)

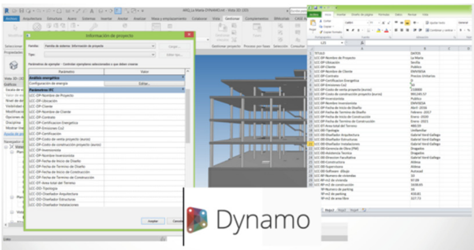

Fig. 20. Link Data, original preparation (2020)

LCC Data Structure Proposal Integrated to IFC

Step 1: A file must be generated with data, which was obtained from the construction cost base of Andalucia (BCCA), Spain. Once we have made the model, each of the data

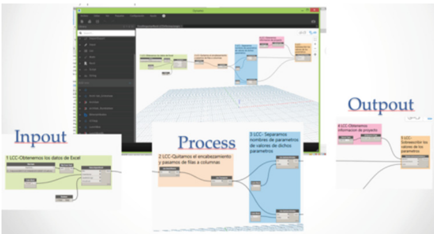

Fig. 21. Script dynamo, original preparation (2020)

will be entered, through a Dynamo script, Fig. 21, so that the model houses the updated costs, Fig. 20.

Costs:

Pre construction

- A0 Land and associated rates/advice

Production stage (A1–A3)

Construction stage

- A5 Construction of civil engineering works.

Usage stage

- Use B1
- Maintenance B2

Final stage of life

- C1 demolition
- C2 Waste disposal.

Step 2: Script development for data link of cost information, which helps us automatically enter data into the BIM model.

With Dynamo we will be able to generate a link between the information in the Excel file to the BIM model, Fig. 22.

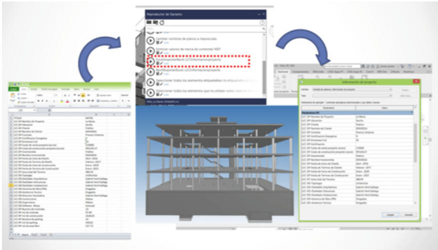

Fig. 22. Script dynamo, original preparation (2020)

Step 3: Export the information in the IFC 2x3 version, so you can openly share the data, Fig. 23.

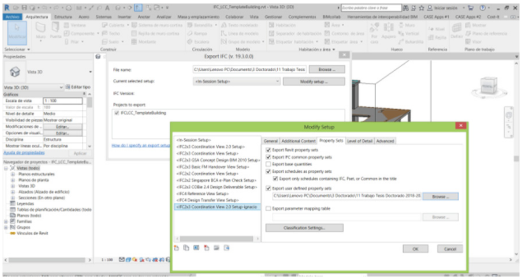

Fig. 23. Export, IFC 2x3 version (2020)

Step 4: The IFC information is displayed, in BIMcollab, to verify that the costs are in the exported BIM model. Below is an example of what the result of the execution would look like, export of the information and we verified that the data is not lost and found in our model (Fig. 24).

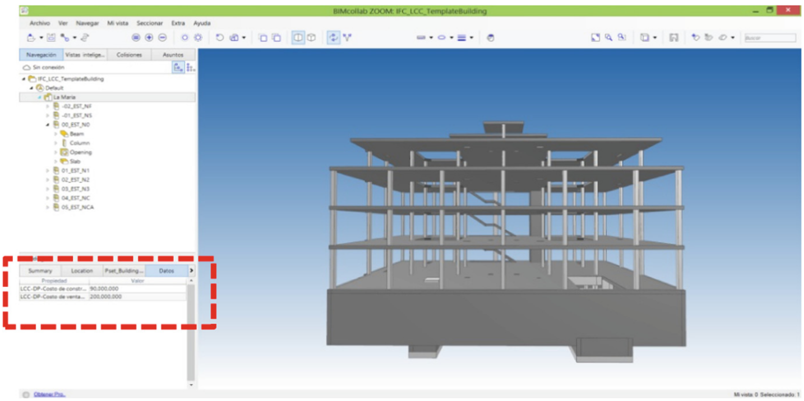

Fig. 24. Results visualization, BIMcollab, original preparation (2020)

5.1 Results

In reference to our main objective, which was to develop a proposal for an IFC structure to implement LCC, using the ISO 15686 methodology, the results were achieved and visualized on a BIM model, a script has been created and applied to be able to apply to any BIM model that has previously been modeled correctly. This makes possible a quick analysis of which parts of our building we could perfect to realize a sustainable architecture.

Regarding the secondary objective of automating the LCC information process on BIM platforms through the use of parametric software, thanks to the Autodesk Dynamo program and a research path to understand its operation and try to apply it to the LCC, an optimal level has been reached Automation, in which after linking the BIM file with Dynamo, a calculation of less than 30 s is performed, which we consider cannot be compared to that performed manually due to the large time difference used in one and the other, being the first infinitely faster than the second.

Our objective of harmonizing the manual calculation process of LCC by using calculation tables has been achieved in a remarkable way thanks to the excel tables that contain the cost information

In summary, we can assure that the main and secondary objectives proposed at the beginning of the study have been satisfactorily carried out.
Advantage:

- You can evaluate the project in two different ways, a total in which all the elements belonging to the model are taken into account and a comparison between two or more elements, which allows you to choose the one that most interests you. In other words, it allows you to select those groups (or elements) that you are interested in analyzing, so it is not necessary to analyze everything to draw partial conclusions.
- The data that is calculated within the BIM model is exported, it can be linked to our cost file.

Disadvantages:

- It is not updated at the moment, if any characteristic of the model is changed, the calculation would have to be redone.
- It cannot be projected at the same time as analyze.
- The analysis is not intuitive or visual directly on the model.

We can affirm after this study that developing a scrip is a good cost analysis tool for a building since it produces a series of graphs that summarize its LCC behavior. However, the great lack that we observe is that of not being able to use the tool at the same time that we are planning the building, but that we have to carry out the project and once the analysis has been done.

5.2 Conclusions

IFC is an emerging technology, created to file sharing, interoperability, including planning and budgeting in the model, which is not currently established for the execution of works. While the various BIM software developers have added a plug to facilitate the work, although not all information is correctly transferred. It is true that there are design and visualization tools that enable really powerful conflict detection and resolution, within the possibilities offered.

Finally, we conclude that the processes and interoperability between software regarding costs, needs further development and should be improved to ensure that the information flow between the model BIM 5D model can be performed satisfactorily.

References

1. Asiedu, Y., Gu, P.: Product life cycle cost analysis: state of the art review. Int. J. Prod. Res. (1998). https://doi.org/10.1080/002075498193444
2. Fleischer, G.A., Khoshnevis, B.: Incorporating economic impact assessment into computer-aided design. In: Proceedings of the American Institute of Industrial Engineers, Annual Conference Conversion (1986)
3. ISO: ISO 15686-5:2017 - Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing (2017). https://www.iso.org/standard/61148.html
4. García-Erviti, F.: El análisis del coste del ciclo de vida como herramienta para la evaluación económica de la edificación sostenible. Estado de la cuestión. Inf. La Construcción. **67** (2015). http://informesdelaconstruccion.revistas.csic.es/index.php/informesdelaconstruccion/article/view/4015
5. Flanagan, R., Kendell, A., Norman, G., Robinson, G.D.: Life cycle costing and risk management. Constr. Manag. Econ. **5**, S53–S71 (1987). https://doi.org/10.1080/01446193.1987.10462093
6. Woodward, D.G.: Life cycle costing - Theory, information acquisition and application. Int. J. Proj. Manag. **15**, 335–344 (1997). https://doi.org/10.1016/S0263-7863(96)00089-0
7. Langdon, D.: Life Cycle Costing (LCC) as a contribution to sustainable construction: a common methodology. Final Methodol. **18**, 48–54 (2007). https://doi.org/10.2478/v10012-011-0017-8
8. Goh, B.H., Sun, Y.: The development of life-cycle costing for buildings. Build. Res. Inf. **44**, 319–333 (2016). https://doi.org/10.1080/09613218.2014.993566
9. Sayed, S.S.M., Sawant, P.H.: Life-cycle cost and financial analysis of energy components in mass housing projects – a case project in sub-urban India. Int. J. Sustain. Built Environ. **4**, 202–221 (2015). https://doi.org/10.1016/j.ijsbe.2015.07.001
10. Higham, A., Fortune, C., James, H.: Life cycle costing: evaluating its use in UK practice. Struct. Surv. **33**, 73–87 (2015). https://doi.org/10.1108/SS-06-2014-0026
11. Islam, H., Jollands, M., Setunge, S., Ahmed, I., Haque, N.: Life cycle assessment and life cycle cost implications of wall assemblages designs. Energy Build. **84**, 33–45 (2014). https://doi.org/10.1016/j.enbuild.2014.07.041
12. König, H., De Cristofaro, M.L.: Benchmarks for life cycle costs and life cycle assessment of residential buildings Build. Res. Inf. **40**, 1–23 (2012). https://doi.org/10.1080/09613218.2012.702017
13. Moore, T., Morrissey, J.: Lifecycle costing sensitivities for zero energy housing in Melbourne, Australia. Energy Build. **79**, 1–11 (2014). https://doi.org/10.1016/j.enbuild.2014.04.050
14. Tokarik, M.S., Richman, R.C.: Life cycle cost optimization of passive energy efficiency improvements in a Toronto house. Energy Build. **118**, 160–169 (2016). https://doi.org/10.1016/j.enbuild.2016.02.015
15. buildingSMART International: buildingSMART (2019). https://www.buildingsmart.org/
16. Zhang, C., Beetz, J., Weise, M.: Interoperable validation for IFC building models using open standards. J. Inf. Technol. Constr. **20**, 24–39 (2015). https://doi.org/10.18154/RWTH-CONV-213541

17. ISO 16739-1:2018: ISO 16739-1:2018 Preview Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – Part 1: Data schema. Int. Organ. Stand. (2018)
18. Lilis, G.N., Giannakis, G.I., Rovas, D.V.: Detection and semi-automatic correction of geometric inaccuracies in IFC files. In: 14th Conference of International Building Performance Simulation, BS 2015 (2015)
19. Laakso, M., Kiviniemi, A.: The IFC standard - a review of history, development, and standardization. Electron. J. Inf. Technol. Constr. **17**, 134–161 (2012)
20. Autodesk, Revit IFC manual (2018).
21. https://www.autodesk.co.uk/campaigns/interoperability/ifc-handbook
22. Giannakis, G.I., Lilis, G.N., Garcia, M.A., Kontes, G.D., Valmaseda, C., Rovas, D.V.: A methodology to automatically generate geometry inputs for energy performance simulation from IFC BIM models. In: 14th Conference of International Building Performance Simulation, BS 2015 (2015)
23. Dimyadi, J., Spearpoint, M., Amor, R.: Sharing building information using the IFC data model for FDS fire simulation. In: Fire Safety Science (2008). https://doi.org/10.3801/iafss.fss.9-1329
24. Varios, Spanish journal of BIM 14/01, Spanish J. BIM (2015)
25. Yung, P., Wang, X.: A 6D CAD model for the automatic assessment of building sustainability. Int. J. Adv. Robot. Syst. (2014). https://doi.org/10.5772/58446
26. Van Berlo, L.: Future technology Presentation buildingSMART Summit Beijing. https://www.linkedin.com/pulse/future-technology-presentation-buildingsmart-summit-l%C3%A9on-van-berlo/
27. http://biblus.accasoftware.com/es/ifc-que-es-y-relacion-con-el-bim/
28. Ramirez, D.S.: Desarrollo instrumental de ACV en plataformas BIM: Herramienta paramétrica de visualización de resultados, Trabajo Fin de Master (2018)
29. ISO 21931-2:2019: Sustainability in buildings and civil engineering works — Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment — Part 2: Civil engineering works (2019)
30. García-Erviti, F., Armengot-Paradinas, J., Ramírez-Pacheco, G.: Life cycle cost analysis as an economic evaluation tool for sustainable building. Sate of the art, Madrid (2015)
31. OCCS Development Committee Secretariat: About OmniClass. 02/01/2019, de OCCS Development Committee Secretariat Sitio web (2017). http://www.omniclass.org/about/
32. NATSPEC BIM: NATSPEC National BIM Guide - BIM Object/Element Matrix Manual v1.0. 02/01/2019, de NATSPEC BIM Sitio web (2011). https://bim.natspec.org/documents/natspec-national-bim-guide
33. Delany, S.: CLASSIFICATION. 02/01/2019, de NBS BIM Tool Kit Sitio web (2018). https://toolkit.thenbs.com/articles/classification
34. McPartland, R.: What is Uniclass 2015? 02/01/2018, de NBS BIM Tool Kit Sitio web (2017). https://www.thenbs.com/knowledge/what-is-uniclass-2015
35. CSI and CSC: UniFormat™ A Uniform Classification of Construction Systems and Assemblies. 02/01/2018, de Graphisoft Sitio web (2010). https://graphisoft.akamaized.net/cdn/ftp/techsupport/downloads/interoperability/UniFormat_2010m.pdf
36. (2016–2017). BIM Execution Plan v07, New Zealand International Convention Centre. 30/08/2018, de FLETCHER
37. The Construction Specifications Institute and Construction Specifications Canada: MasterFormat® Numbers & Titles. 02/01/2018, de The Edmonton Construction Association (ECA) Sitio web (2016). https://www.edmca.com/media/35207/masterformat-2016.pdf
38. BNA: NL/SfB–Tabellen Inclusief gereviseerde Elementenmethode ’91. 03/01/2019, de STABU NL Sitio web (2005). https://www.stabu.nl/mijnstabu/files/NL-SfB_BNA_Boek_2005-ISBN-10%2090-807626-3-6.pdf