Design Process Maturity Level: the Four Interfaces

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Abstract

AIA's level of development concept describes the completeness degree for a given element of the BIM model towards a previously defined reference. This proposition contemplates the levels of development of constructive elements organized from the Uniformat classification. Although this criterion properly specifies different sectors or systems of a building, it may lead to incomplete, compartmentalized views on the design, if understood separately. The original concept of level of development, called LOD in the literature, addresses two meanings – it is treated as level of detail, as well as level of development, which shows contradictions.

The paper´s objective is to propose a new concept to resolve these contradictions and expand the meaning to the concept of Maturity Level, as a measure of the developing a design against to its previously set targets.

Keywords: Design Process, Level of Detail, Level of Development, Maturity

1 Introduction

AIA's level of development concept describes the completeness degree for a given element of the model towards a previously defined reference. This proposition contemplates the levels of development of constructive elements organized from the Uniformat classification. Although this criterion properly specifies different sectors or systems of a building, it may lead to incomplete, compartmentalized views on the design, if understood separately.

The original concept of level of development, called LOD in the literature, addresses two meanings – it is treated as level of detail in the (AIA 2007), (PennState 2010), (Authority 2012) and (VICO, 2012), as well as level of development in BIM Protocol Exhibit (Architects 2008), which shows contradictions, (Manzione 2013).

We have noticed that AIA itself makes no distinction between both concepts, accepting the two as synonyms, which is confirmed by an AIA's document on IPD, (AIA 2007).

In the illustrative documents on LOD, usually the figures relating to the concept relate LOD to the idea of increasing geometric details, which may lead the user to understand BIM solely as a synonym for 3D representation. We understand as necessary to review the concept of Level of Development, extending it to Level of Maturity and adding parameters to allow assessing the combination of other aspects, including the level of detail itself, in order to solve conceptually the indicated contradictions.

We, thus, propose a new definition as this paper's goal.

2 Maturity level

Maturity level is the measurement of development for a design in relation to its previously defined goals. This goal reference comprises business objectives – translated into programmatic requirements; BIM pre-defined uses – translated into specific sets of geometric and non-geometric properties; by geometric compatibility; and by the planning and control system (Figure 1). The Maturity Level is a framework to study the main references to measure the maturity of a project. This definition is a part of first author's PhD Thesis (Manzione 2013) and the **focus of this paper is determine, detail and stablish a methodology to LOD calculation only.**

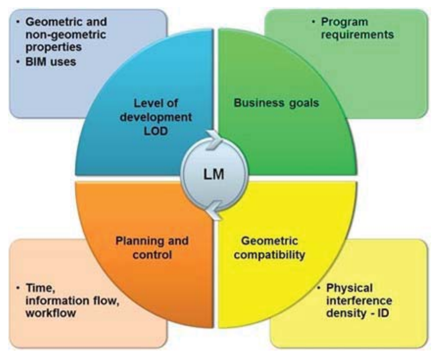

Figure 1: Design Process Maturity Level: the Four Interfaces

2.1 Level of development - geometric and non-geometric properties

Although professionals, in the practice, know definitions for development phases in a project in the conventional process there are problems that restrain checking compliance to requirements in each phase.

One reason is that both the applicable regulations, (ABNT 1995) and the project scope manuals, project Managers and Coordinators Association, set the boundaries for phases but do not specify objective criteria, but concepts. The other reason is that the checking process is manual, hence not accurate, giving room for incomplete checking and subjectivity. Similar problems also happen in BIM universe: the concept adopted by the (AIA 2007) to classify levels of development emphasizes the model geometric evolution and places a relatively less relevance to non-geometric properties.

This concept may reinforce to users the idea that BIM is just a geometric model, stressing the standpoint of (Owen et al 2010), who notice that "the current trend for many is to use BIM more as a technology, which they call 'simple BIM' (sBIM) and less as a smart, integrated process (iBIM)". We understand that within the conceptual structure there must be an important portion related to the association of BIM uses for each element of the model and for each phase of the project.

This concept failure is also present in some BIM implementation manual: the Penn State manual (PennState 2010) works with the level of detail concept, even proposing a spreadsheet for defining information for the exchange between specialties. This spreadsheet is a useful tool for the planning process preparation phase, however it does not directly relates the necessary information with property types existing in IFC and do not formulate how objectives determined will be measured.

2.2 Theory

In order to allow an assessment of the development of a project in BIM, it is necessary to elaborate an objective method to measure properties and relate results with the level of development. Researching the topic, we use as reference for developing the measurement of properties in BIM the work of (Sacks & Tribelski 2010). This work was developed in projects using the CAD 2D technology, and consisted in surveying several indicators for the project process in this environment. In order to build these indicators, the authors defined some preliminary concepts:

A "**information package** is a view on a drawing, a text document, a spreadsheet, a data table and so on, or hard copies or a computer file". As the communication means used in the experimentation were CAD 2D drawings, information packets were the basic units transferred between the project team, but the authors stress that if BIM is used the information package may represent a complete model or a subset of a model.

An "**information item**" is a fragment of information that may be text (a number in a quantity list), a dimension in a drawing or a graphic element as a line, arc or a texture in a drawing.

An information package, thus, represent a set of information items. An "**information object**" is a typical component of a building with attributes and technical characteristics as shape, function and defined behavior.

An information object is defined from its representations, lists and documents, which are defined as "information packages". As 2D representations, each information object will appear in several packets due to the redundancy existing in 2D representation. An "information attribute" is an attribute of an information object, such as physical and mechanical properties, color, price and so on. For the same reason aforementioned, "information attributes" will appear in several information packages.

The authors propose the utilization of automatic means to count the physical size of the information packet in terms of word or graphic objects counting or file size in kB, but these measures do not reflect the packet content with accuracy. A change in the physical size of an information package does not necessarily reflect the increase or decrease of information content that is transferred.

From these preliminary concepts, the authors defined the "package size" indicator as an index quantifying the level of detail of information contained in a given drawing lot. According to the authors, this indicator allows to assess the detail increase rate by the approximated degree of completeness of the project. The indicator is based in the counting of information units and can be formulated in two levels of detail: by the counting of information objects and their attributes in an information packet or by counting the information items in the packet.

The package size can be used to monitor the accumulation rate of new information or in relative or absolute terms. In relative terms, the information package size can be compared with the size of a version of the same package to determine the percentage of increase.

In any time t, the information package is defined by the equation (1).

$$Tp = \sum_{i=1}^{nIO} nIA_{\iota}^{\dot{v}} \quad (1)$$

In which the terms are:

$nIA_{\iota}^{\dot{v}}$ = the number of attributes belonging to the information object *i* that that values attributed to it in the time *t*, and nIO is the total number of information objects in the package.

However, if a measure of the package completeness is required, an absolute measurement must be used. This requires an estimative of the final size of the information package. It can be estimated based in similar packages or carefully planning the information content required in each package. The authors conclude by commenting that, in BIM, this indicator can be automated and thus, simplifying the application of the indicator.

As it is manual, the method has limitations, and repetitions of the same information packages can happen when using drawings in CAD 2D. Figure 2 shows the idea adopted for the conceptual structure: the levels of development varying from 100 to 500 being associated to different property types that might be created by the user due to the type of use planned for BIM and applied to the building objects that will be categorized according to the Uniformat.

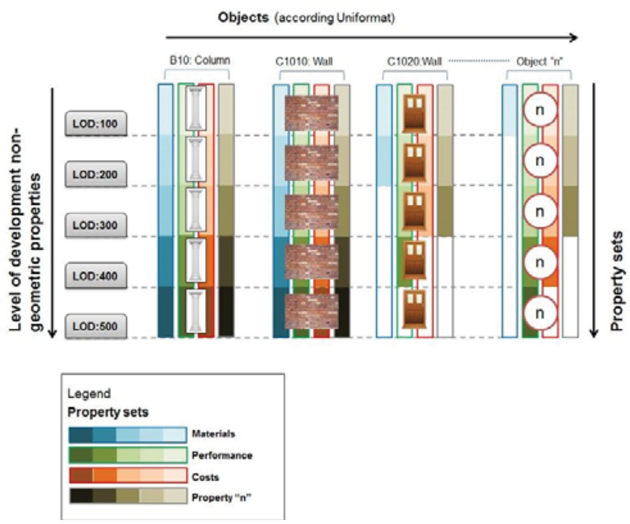

Figure 2: Level of development and property sets

2.3 Calculation methodology for LOD

The calculation is carried out by means of an Excel spreadsheet and the Solibri software, and many other software performing the same operations can be used.

The steps for the calculation will be provided below from an example.

Step 1: to count the number of objects of the BIM model with Solibri, ranking them according to Uniformat criteria – here, it is important to check whether the model has "not classified" objects and, if that is the case, perform the corrections, because a modeling that does not take into account this may lead to errors (Figure 3).

Information Takeoff | Takeoff All | Building Element Quant... | Report

Building Element Type	Component	Count
B1010 Floor Construction	Beam	1,655
B1010 Floor Construction	Column	133
B1010 Floor Construction	Slab	1,257
B1020 Roof Construction	Roof	4
B2020 Exterior Windows	Curtain Wall	226
B2020 Exterior Windows	Wall	112
B2020 Exterior Windows	Window	85
B2030 Exterior Doors	Door	690
C1010 Partitions	Wall	3,330
C2010 Stair Construction	Stair	72
C2020 Stair Finishes	Railing	68
C3030 Ceiling Finishes	Suspended Ceiling	193
E1090 Other Equipment	Furniture	337
E1090 Other Equipment	Object	428

Figure 3: Count objects through Solibri

Step 2: generate an analytical report in Solibri to classify objects due to the property type being researched. With this report, we will be able to identify objects with or without attributed values for the property (Figure 4).

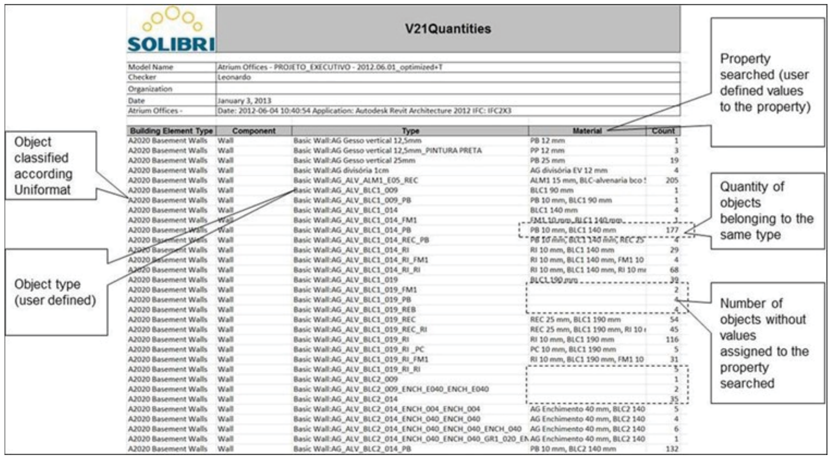

Figure 4: Example of analytical report of the objects and properties

Step 3: export data to the Excel spreadsheet that will perform all calculations (Figure 6).

Figure 9 is presented with formula used, allowing thus that it may be created and used by other researchers. Numbered fields are highlighted and will be identified and explained below.

Field 1: fill with the total number of objects of the Uniformat class that is being analyzed. In the figure example, the spreadsheet for the class C1010 – walls was used.

Field 2: fill with data obtained from the Solibri analytical report as per Figure 4. All objects that have attributed values for the property set in study are placed in this field, irrespective of whether these values are validated or not according to the requirement program.

Field 3: analyze results obtained from the Solibri report in the Figure 5 and check whether they comply with the requirement program. Lacking the requirement program or if it is outdated, then data can be inserted only upon undergoing a critical analysis and validation process carried out by the design coordination, the owner and the professional in charge of the specific design.

Field 4: this is an automatically calculated field. It counts the number of property types that are being considered in the chosen property set. The number of properties for the chosen set will serve as the weight to be attributed for the item.

Field 5: this is an automatically calculated field. It is calculated the arithmetic average between the number of objects divided by the number of property types, which were calculated in Field 4. The average obtained of objects are related to the Field 2 and is calculated only to be a referential. The value that will be effectively adopted is that was described in field 3.

Field 6: this field automatically calculates the "grade" obtained in the item, showing "how much" of the item is met. This data is obtained by dividing the average number of properties meeting requirements – as calculated in field 5 – by the total number of objects.

Field 7: this is an automatically calculated field. Here, the weights are summed up – which were calculated in field 4.

Field 8: this is an automatically calculated field. Here, the weighted average of item grades is calculated and then multiplied by its weights and divided by the sum of the weights.

Field 9: this field calculated automatically the LOD value through the weighted average – calculated in field 8, transformed into percent and multiplied by the theoretical LOD value of the phase (in the example, equal to 100, however this value may be 200, 300, 400 or 500, depending of the phase in study).

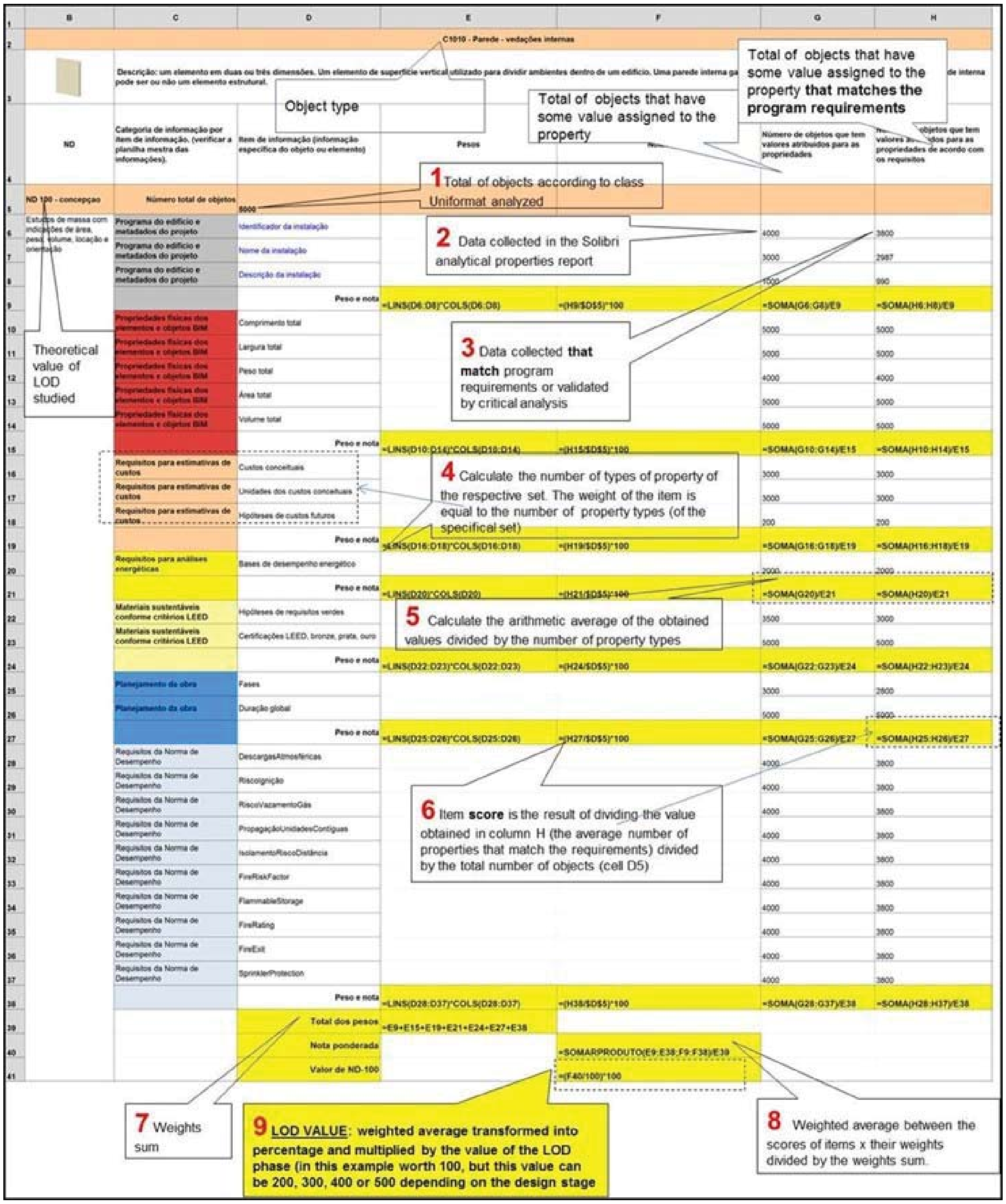

Figure 5: LOD spreadsheet

2.4 LOD data as a Key Performance Indicator

Data profile

Objective: to assess the design's level of development as a whole or of a specific discipline.

Measurement type: quantitative.

Stage with higher impact: as the indicator is applicable to all design phases, impact happens in all of them.

Data collection period: at each updated done to the BIM model for the specific discipline or in the central model.

Report issuance timetable: reports must be issued at every model update and before design coordination meetings.

Targets

Trend: by analyzing the calculation methodology we find that as the LOD obtained is near to the theoretical LOD of the design phase, better is the performance so its trend is good as its value increases.

Parametrization

The level of development is a relative value and it depends on what is agreed between the agents. It depends of the specific uses applied to BIM, since the associated property set is directly linked to the use of BIM. Properties can also be extended through the development of new property sets or reduced due to the agreement.

Absolute classification will depend on the standard development from regulation or specifications from professional associations, government and others.

3 Case study

The LOD key performance indicator may be applied in design diagnosis or evolution tracking.

For this, two cases were selected. The first one is the design development follow-up and its twenty versions were analyzed using these indicators. In the second case, an already concluded BIM model was obtained and the indicators were applied to it.

Their application was possible in both cases and results and profile conditions are developed throughout the paper.

3.1 Case 1

The first case consists of an office building design with low technical complexity, with the goal to isolate the model from other factors related especially to the technical difficult of using modeling software by design professionals.

The company responsible for the architectural design developed the model aiming to generate drawings. The exchange between professionals was carried out through the dwg format, since only the architecture firm used BIM for the design.

The company opted for the Revit modeling software, where the team has more ability due to the tool being in use for four years, according to the design coordinator.

The building's design comprises the following specialties: architecture, frames, acclimatization, elevators, concrete structure, metallic structure, foundations, electrics, hydraulics, interiors, lightning and landscaping. The architectural design firm itself coordinates the design. Of all specialties listed, only architecture is using a BIM model according to the design coordinator. The structure specialty is also being modeled in BIM, however instead of exporting by the TQS software, the firm decided to model the specialty itself.

The reason is the lack of interest on BIM by the structural design firm that was hired for the design, and on the telling that exporting through the TQS software creates quality issues as failures on inclined beam and curved surfaces representation among others.

The modeling process in BIM takes place concurrently to the conventional design process as other companies develop it. In this case, BIM is being used only for generating drawings to serve as reference for other designers. Designs compatibilization was achieved manually by the architecture firm. It was also seen that the company does not set apart professionals in charge of the architecture and structure model in their functions. The model was built by mixing both disciplines, without divisions that might identity the use of a model analytical structure.

3.1.1 LOD calculation

The executive design phase corresponds to the level of development LOD 400 in the conceptual structure and measurements are referenced to this value. As the BIM model objective was only generating documents, the property set used in the BIM element matrix was "manufacturer information requirements".

The set of these properties stipulates the following information for LOD 300: type, material, and availability. For LOD 400, these are: manufacturer's name, service provider name, serial number, Uniformat classification number, inventory number, model number, purchase order number, product ID, product name, production year and accessories.

By analyzing information that is available and BIM objectives, a decision was made to analyze separately the "material" property maintained by the *IfcMaterial.Name* class.

The Solibri software was used and the reading of the specified material name was carried out. The LOD calculation was performed according to the methodology proposed in this paper.

3.1.2 Results analysis

Test results were tabulated in Figure 6, which was structured due to the number of model versions and objects that were classified according to Uniformat by the design's author. For every version, the amount of objects found in the model was tabulated and the percentage of objects that had values assigned to their properties was calculated. At the end, according to the proposed method, the weighted average among objects and the percentage met for every material was calculated. Such weighted average was converted into percentage and then multiplied by the required LOD value for that phase.

Figure 8 shows the LOD series as obtained across the twenty versions of the model.

Although initially the model had 5,500 objects and at the end, they were 8,600, it was noted that the LOD did not present much variation, keeping at the average of 272.

The chart point in version 11 refers to a modeling error, confirmed by the author, were type E 1090 objects suddenly went to 11,597 from 859 and later remained in their initial average, ending with 765 objects. Using LOD allowed for a quick and clear indication the occurrence of such error.

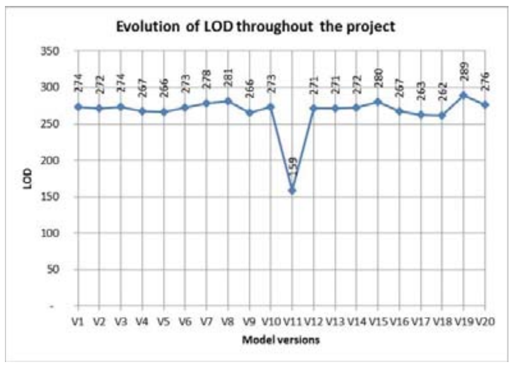

Figure 6: Evolution of LOD

The analysis of Figure 7 helps identify that object types A2020, B1010, and C3020 were the most had values assigned to the property while the material objects of other types-C2010 construction of stairs, windows external-B2020, B2030-E1090-external doors and other equipment had not even value for the property.

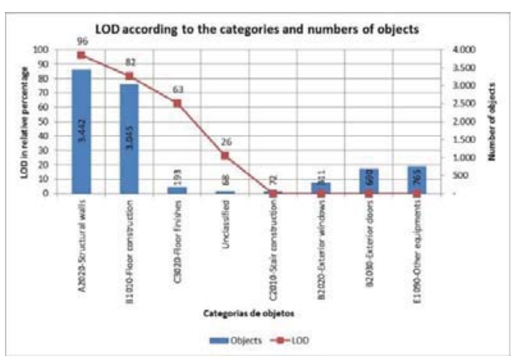

Figure 7: LOD according to the categories and numbers of objects

3.1.3 Discussions

The average indicator is 272, well behind the expected value – 400. However, the drawings were visually inspected and presented good quality, including the specification of the majority of materials and then, considered as reasonable for executing and budgeting the work. By investigating such discrepancy, it was noted that the firm did not used fully the registered property within objects for specifying materials in the drawings. It was notes that tags were manually inserted. Thus, some traditional methods continued to be applied, which explains the low LOD.

As not all other agents used the BIM model, including the contractor itself, the architect team felt demotivated to search for more accuracy to have a better LOD.

Another comment must be done about the Uniformat classification used in the model, as several "unclassified" objects were found while others were incorrectly classified.

For instance, the A-2020 classification is denominated in the original as basement walls. However, looking at the model it was noted that these walls should be classified in the categories B2010 – internal walls and C-1010 – internal sealing.

Another failure found was in the classification C3020 – floor finishing, as the elements in the model under such classification were actually linings, so the classification would have to be changed to C-3030 – lining finishing.

On its turn, floor finishing was incorporated to B1010 type – floor construction. Actually, this class covers the structure elements, but its name can cause confusion. What happened, by seeing the source file in .rvt format, was the creation of an object comprising the floor and its finishing. The Revit software, by exporting objects composed in IFC format, transforms them into single objects but preserving properties, which allowed for their reading.

As Revit has problems at generating IFC, the analysis was limited as the reduction in the number of objects introduces errors and makes difficult to analyze the value of properties.

It was not possible to compare values obtained in the objects against values required in the program, as the program was not fit for that. As for this aspect, the author informed that at the beginning of the modeling, objects were prepared according to specification. This information was checked and confirmed in the model analysis, as the majority of variations taking place were addition, elimination or edition of geometric properties only.

For this reason, the LOD calculation was simplified however guaranteed by the information provided.

3.2 Case 2

This case has different aspects from the first one. The BIM model was developed by a general contractor company in São Paulo and elaborated along with a series of five BIM models as a prototype for implementing the BIM technology in this company.

This BIM implementation design had much visibility in the market and was referenced by other companies. The model objective is to make possible the extraction of quantitative for budgeting.

In this case, the LOD was applied in order to diagnose the model, once the design process was not followed-up. The disciplines modeled were architecture and structure.

3.2.1 LOD calculation

Figure 8 features a segment of the survey spreadsheet and object and property analysis.

Building Element Type	Component	Type	Material	Count
A2020 Basement Walls	Wall	Alvenaria:-:Bloco concreto 14cm	Alvenaria:-:Bloco concreto 14cm	70
A2020 Basement Walls	Wall	Alvenaria:-:Bloco concreto 19cm	Alvenaria:-:Bloco concreto 19cm	39
A2020 Basement Walls	Wall	Alvenaria:-:Bloco concreto 9cm	Alvenaria:-:Bloco concreto 9cm	2
A2020 Basement Walls	Wall	Alvenaria:-:Enchimento	Alvenaria:-:Enchimento	6
A2020 Basement Walls	Wall	Drywall:-:Drywall 10cm - Placa Standard	Drywall:-:Drywall 10cm - Placa Standard	4
A2020 Basement Walls	Wall	Gesso:-:Gesso Liso	Gesso:-:Gesso Liso	32
A2020 Basement Walls	Wall	Gesso:-:Gesso Liso A. Molhada	Gesso:-:Gesso Liso A. Molhada	6
A2020 Basement Walls	Wall	Revestimento Cerâmico:-:Atlas cor branca - 5x5	Revestimento Cerâmico:-:Atlas cor branca - 5x5	54
A2020 Basement Walls	Wall	Revestimento Cerâmico:-:Atlas cor bálsamo - 5x10	Revestimento Cerâmico:-:Atlas cor bálsamo - 5x10	15
A2020 Basement Walls	Wall	Revestimento Cerâmico:-:Atlas cor tabaco - 5x5	Revestimento Cerâmico:-:Atlas cor tabaco - 5x5	18
A2020 Basement Walls	Wall	Alvenaria:-:Bloco concreto 14cm	Alvenaria:-:Bloco concreto 14cm	28
A2020 Basement Walls	Wall	Alvenaria:-:Bloco concreto 19cm	Alvenaria:-:Bloco concreto 19cm	37
A2020 Basement Walls	Wall	Alvenaria:-:Bloco concreto 9cm	Alvenaria:-:Bloco concreto 9cm	2
A2020 Basement Walls	Wall	Alvenaria:-:Enchimento	Alvenaria:-:Enchimento	4
A2020 Basement Walls	Wall	Drywall:-:Drywall 10cm - Placa Standard	Drywall:-:Drywall 10cm - Placa Standard	4
A2020 Basement Walls	Wall	Gesso:-:Gesso Liso	Gesso:-:Gesso Liso	30
A2020 Basement Walls	Wall	Revestimento Cerâmico:-:Atlas cor branca - 5x5	Revestimento Cerâmico:-:Atlas cor branca - 5x5	25
A2020 Basement Walls	Wall	Revestimento Cerâmico:-:Atlas cor bálsamo - 5x10	Revestimento Cerâmico:-:Atlas cor bálsamo - 5x10	53
A2020 Basement Walls	Wall	Revestimento Cerâmico:-:Atlas cor tabaco - 5x5	Revestimento Cerâmico:-:Atlas cor tabaco - 5x5	18

Figure 8: Segment of the survey spreadsheet

As it is a model aiming to perform quantitative surveys, the expected LOD is 400 with material specification properties and accurate geometry.

The test followed the proposed methodology and results are available in Figure 9.

	Objects	LOD
A2020 Basement Walls Total	19.737	98,80
B1010 Floor Construction Total	14.767	99,23
B2020 Exterior Windows Total	1.148	-
B2030 Exterior Doors Total	1.733	
E1090 Other Equipment Total	3.916	-
Unclassified Total	1.095	
Total of objects	42.395	
Weighted average		79,74
LOD calculated for LOD expected 400		318,98

Figure 9: Results of ND calculation

3.2.2 Discussions

Results obtained showed almost 80 percent reached, resulting in a LOD of 318,98.

Material property was not specified for the B-2020 group. These are aluminum frames and, in this case, objects can be reused later. However, minimum specifications must be added, such as color, coating type or anodizing, glass thickness and types, accessory brands and more. Equally, the B-2030 group, comprised by doors, could have been specified. It is a relatively simple specification, which includes door characteristics: if it will be coated or varnished and the type and brand of hardware used. The lack of this specification damages the amount survey for budget. By reading the E-1090 group, it is possible to note a large disorganization (Figure 10).

E1090 Other Equipment	Object	IFC--IfcBeam 39		1
E1090 Other Equipment	Object	IFC--IfcBeam 43		1
E1090 Other Equipment	Object	IFC--IfcBeam 46		1
E1090 Other Equipment	Object	IFC--IfcBeam 68		1
E1090 Other Equipment	Object	IFC--IfcMember		1
E1090 Other Equipment	Object	IFC--IfcMember 426		1
E1090 Other Equipment	Object	IFC--IfcMember 429		1
E1090 Other Equipment	Object	IFC--IfcMember 430		1
E1090 Other Equipment	Object	IfcBeam : IFC:IfcBeam		251
E1090 Other Equipment	Object	IfcMember : IFC:IfcMember		161
E1090 Other Equipment	Object	--		15
E1090 Other Equipment	Object	Acabamento - Gesso 0.5cm		1
E1090 Other Equipment	Object	Ferro:Tela Metálica		2
E1090 Other Equipment	Object	Paisagismo:Piso Cimentado Polido		1
E1090 Other Equipment	Object	Paisagismo:Terra		2
E1090 Other Equipment	Object	Terreno:Lote		1
E1090 Other Equipment	Object	Terreno:Rua		1
E1090 Other Equipment	Object	Terreno:Terreno		1
E1090 Other Equipment	Object	:		2
E1090 Other Equipment	Object	--		7

Figure 10: Problems of lack of organization in the group E-1090

Conclusions

The paper show that is possible to measure LOD. Based in the two cases next improvements could be in automatizing the calculation routine and stablish a way to measure properties values against the client's program. On the other hand, the LOD calculation has some restrains and caveats, as commented below.

Pre-existing properties in the designer object library (default).

Usually, designer's object library is developed and its use must be done carefully, as we can have property sets not specified to exist; properties with values attributed a priori and objects with incorrect or unnecessary geometric details are factors that may lead to deceiving LOD measurement. For this reason, it is recommended that before the design process all members review their libraries and perform the necessary adjustments.

Absence, incompleteness or outdating of the requirement program.

It is not frequent in the work practice for the client to formally enter the program requirements, since it is common for this to happen informally and at several process phases. However, it is necessary to distinguish the client requirements – performance requirements by definition – from those eminently technical, specific of the design specialties involved. Thus, previously filling a table with all requirements specified seems not feasible, and it is recommended that the result assessment be based also in qualitative critical analyses, not only in numerical analyses.

Rework

The LOD indicator is not focused to measure rework, but it exists in practice and can change LOD values, so rework affects the design's level of development.

Rework can happen from a combination of several factors: objects can be eliminated or changed in their geometric or non-geometric properties, new objects can be created and new program requirements can be created or phased out. A change combining these factors cannot be considered as rework without analyzing the causes. Changes happen both to improve as to damage the process. However, how can this be assessed? Just accounting for the amount and type of change do not lead to a conclusion, only to evidences of changes.

We understand that the rework can only be assessed through the design coordinator interpretation along with his/her team, analyzing and assessing impacts and the nature of changes.

Geometry accuracy

The terms "approximated geometry" and "accurate geometry", albeit common in LOD current definitions, are not so precise to assess the model development. If the model objective is to pre-manufacture concrete or metallic structures or even components such as hydraulic kits or restrooms, the required "precision" for manufacturing processes ranges in the millimeter. The required accuracy for conventional construction ranges in the centimeter for most cases. Another point to consider is measurement confirmation, because in a LOD of 200 objects can be inserted only for macro definition as solutions or parties; however, in a superior stage of development, it will be required to confirm measurements, since objects will be compatibilized and detailed. In all cases, accuracy must be understood within the context where it is inserted and its assessment must be performed with these considerations in mind.

References

AMERICAN INSTITUTE OF ARCHITECTS (2007) *Integrated Project Delivery: A Guide.*

AMERICAN INSTITUTE OF ARCHITECTS. (2008) *BIM Protocol Exhibit.*

AUTHORITY, B. A. C. (2012) *Singapore BIM Guide.*

MANZIONE, L. (2013) *Proposition for a Collaborative Design Process Management Conceptual Structure using BIM.* PhD Thesis, Universidade de São Paulo.

NBR 13531 ABNT (1995) - *Elaboração de projetos de edificações - Atividades técnicas.*

OWEN, R., AMOR, R., PALMER, M., DICKINSON, J., TATUM, C., KAZI, A. S., PRINS, M., KIVINIEMI, A. & EAST, B. (2010). Challenges for Integrated Design and Delivery Solutions. Architectural Engineering and Design Management, 6, 232-240.

PENNSTATE 2010. *BIM Execution Planning Guide.*

SACKS, R. & TRIBELSKI, E. (2010) *An empirical study of information flows in multi-disciplinary civil engineering design teams using lean measures.* Architectural Engineering and Design Management.

VICO. (2012) Model Progression Specification [Online]. Available: http://www.vicosoftware.com/model-progression-specification/tabid/85227/Default.aspx