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Approach For Evaluation Of Cost And Environmental Impacts Of Buildings Using BIM Objects

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ABSTRACT: *Acrosstheworld, Building Information Modeling (BIM) is transforming architecture, engineeringandconstruction (AEC) industry. Itscontributionshavemotivatedmany countries tosystematicallyimplementit in all constructionprojects. In sub-SaharanAfrica, BIM is just beginningand its spreadingrequires a strong involvementofinstitutionsdedicatedtotrainingandresearch in civilengineering. In thiscontext, thisarticleproposes an approachfor automatic evaluation of cost and environmental impactsofbuildings in Cameroonusing BIM objectsof LOD 300. The proposedapproachis applied toimplement, on Revit 2018 platform, BIM objects that integrate theircost and environmental impacts (namelyenergyconsumption, waterconsumption, contributionto global warming, photochemicalozoneformation, atmosphericacidification, eutrophization, aquaticecotoxicity, productionofultimatewaste). The design of a classroom on Revit 2018 platformshowsthat these BIM objects enable cost and environmental impactsevaluationofthewholeconstructionprocesswith a maximum deviation of 0.3%, comparedtoclassicalmanualevaluation.*
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KEY WORDS:*BIM Objects, Cost, Environmental Impacts, Revit, Buildings, Cameroon*

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I. INTRODUCTION

Across the world, Building Information Modeling (BIM) is transforming the practices in architecture, engineering and construction (AEC) industry. Based on BIM software, Integrated Project Delivery (IPD) and Industry Foundation Classes (IFC), this approach improves quality, reduces cost and eases management of civil engineering projects (Celnik and Lebègue, 2015). For these reasons, the level of BIM adoption is over 90% in several countries of North America, Europe and Oceania; a similar dynamic has already started in Asia and South America. In Sub-Saharan Africa, especially in Cameroon, BIM remains underexploited for realization of construction projects and we can observe cost increases and low environmental performance of buildings (Okpwe and Mamba, 2019).

Currently, evaluation of costs and environmental performance of buildings is carried out by using databases and combining several specialized BIM tools: BIM 3D modeling tools, tools for producing 4D models, tools for cost estimation (BIM 5D), tools for environmental impact analysis (BIM 6D) (Celnik and Lebègue, 2015). In order to accelerate this evaluation process, Lee et al. (2015) developed a model that includes environmental impacts within material database of Revit platform. More recently, (Durao et al., 2019; Santos et al., 2019) have settle foundations for integration of environmental data within BIM objects in order to improve efficiency of environmental impact evaluation.

In this context, using Revit 2018 platform and integrating specific data into BIM objects, this paper proposes an approach for automatic evaluation of cost and environmental impacts of buildings in Cameroon. Structured in four (04) sections, it presents: methodology proposed fordevelopment of BIM objects and associated results (Section II); a case study using the developed BIM objects for designing a classroom in Cameroon (Section III) and conclusion (Section IV).

II. PROPOSED METHODOLOGY FOR DEVELOPMENT OF BIM OBJECTS

To develop BIM objects, we have used a methodology organized in four main stages (Figure 1): identification of construction products; collection and update of data related to construction products; description of structure of objects; implementation of BIM objects.

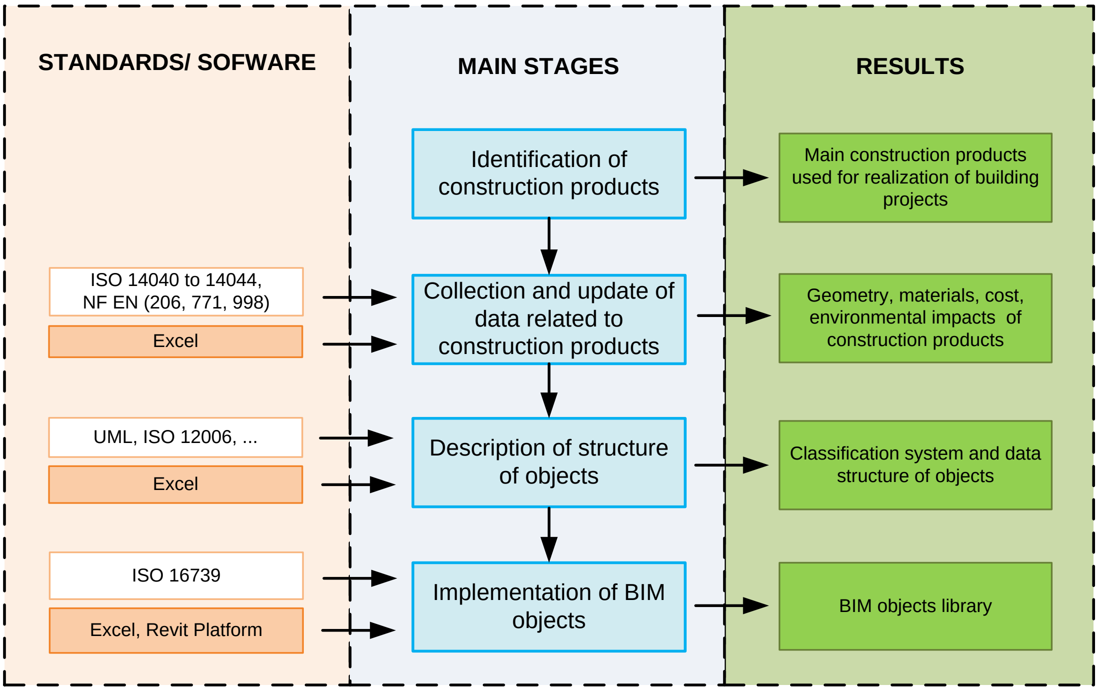

Figure 1:Proposed methodology

2.1 Methodology for identification of construction products

According to European Directive No. 89/106/EEC, a construction product is a manufactured product which can be incorporated, assembled, used or installed in civil engineering works (Conseil des CommunautésEuropéennes, 1988).

In our work, identification process has been focused on construction products commonly used for realization of building projects in Cameroon and Table I gives an outline of identified products.

Table I. **Outline of construction products commonly used in Cameroonian buildings projects (Mamba, 2013a, 2013b; INS, 2020)**

N°	Part ofbuilding	Constructionproduct	Location of production site
1	Foundations	Shallow reinforced concrete pad	Constructionsite
		Reinforced strip footing	Constructionsite
		Reinforcedconcrete beam	Constructionsite
		Core-filled concrete blocks	Constructionsite
		Solid concreteblocks	Constructionsite
		(Cement) mortarjoint	Constructionsite
		Concrete	Constructionsite

N°	Part ofbuilding	Constructionproduct	Location of production site
2	Walls	Shuttered concrete	Constructionsite
		Concrete blocks	Constructionsite
		Stabilizedcompressedearth blocks	Constructionsite
		Terracottabricks	Constructionsite
		Reinforcedconcretelintel	Constructionsite
		(Cement) mortarjoint	Constructionsite
		(Cement-earth) mortarjoint	Constructionsite
3	Beams/ Columns	Reinforcedconcretebeams/ columns	Constructionsite
		Steel beams/ columns	China
4	Flooring	Wood flooring	Constructionsite
		Ceramictiles	China (60%) and Europe (40%)
		Porcelaintiles	China (60%) and Europe (40%)
		Cementmortar (forsealing)	Constructionsite

2.2Methodology for collection and update of construction product data

At this stage, each identified construction products has been associated to many parameters related togeometry, constitutive materials, physical and mechanical properties, cost and environmental impacts.

Below, we present evaluation methods used to compute cost and environmental impacts of a given construction product.

2.2.1Cost of construction products

2.2.1.1Cost calculation method for raw material

We suppose that raw materials used in building construction projects in Cameroon, come from sale points located inside the Country. Thus, once a raw material is on construction site, its cost can be computed using Formula (1):

$$CM = CAM + QM \times \sum_{i=1}^{i=n}(CT_{Ni} \times DT_{Ni}) \quad (1)$$

Where
CM = Cost of one unit of raw material on site;
CAM = Cost of purchasing one unit of raw material at a sale point;
QM = Mass of one unit of raw material;
CT_{Ni} = Cost of national transport mode no. i per unit of mass and per unit of distance;
DT_{Ni} = Average distance traveled by national transport mode no. i during transportation process from sale point to construction site;
n = Number of national transport modes used to move raw material.

2.2.1.2Cost calculation method for construction products

If a product is manufactured outside construction site, then its cost is computed using Formula (2):

$$CP = CAP + QP \times \sum_{i=1}^{i=m}(CT_{Ni} \times DT_{Ni}) + \sum_{j=1}^{j=n} CTA_j \quad (2)$$

Where
CP = Cost of one unit of product;
CAP = Cost of purchasing one unit of product at a sale point;
QP = Mass of one unit of product;
CT_{Ni} = Cost of national transport mode no. i per unit of mass and per unit of distance;
DT_{Ni} = Average distance traveled by national transport mode no. i during transportation process from sale point to project site;
m = Number of national transport modes used to move product;
CTA_j = Cost of task no. jfor integration of one unit of product into a building;
n = Number of required tasks.

If a product is manufactured inside construction site, then its cost is computed using Formula (3):

$$CP = \sum_{i=1}^{i=m} CM_i \times QM_i + \sum_{j=1}^{j=n} CTA_j \quad (3)$$

Where
CP = Costofoneunitof product;
CM_i = Costofoneunitofraw material no. i on site;
QM_i = Numberofunitofraw material no. i withinoneproductunit;
m = Numberofrawmaterialsmakingupthe product;
CTA_j = Costoftaskno. j forproductionofoneunitofproductorfor its integrationinto a building;
n = Numberofrequired tasks.

2.2.2Environmental impacts of construction products

2.2.2.1Environmental impacts

Environmental impacts selected in our work are part of Life Cycle Assessment (LCA) approach defined by ISO 14040 to 14044 standards.

For each construction product identified, environmental impacts include processes of: extraction, transformation and transportation of raw materials; manufacturing and transportation of construction products on construction site; integration of construction product into a building.

In Table II, we present some information about environmental impacts selected and their associated indicators.

***Table II.* Environmental impacts and associated indicators**

N°	Environmental impact category	Environmental impact	Impact indicator (notation)	Indicator unit
1	Impact category related to resources	Energyconsumption	Amount of energy consumed by product (“Energy”)	MJ/ product
		Water consumption	Amount of water consumed by product (“Water”)	L/ product
2	Impact category related to human health	Contribution to global warming	Equivalent mass of carbon dioxide generated by product (“GWP”)	kg eq-CO_2/ product
		Photochemical ozone formation	Equivalent mass of ethylene generated by product (“Smog”)	kg eq-C_2H_4/ product
3	Impact category related to ecosystems	Atmospheric acidification	Equivalent mass of sulfur dioxide generated by product (“Acidification”)	kg eq-SO_2/ product
		Eutrophization	Equivalent mass of phosphate generated by product (“Eutrophization”)	kg eq-PO_4^{3-}/ product
		Aquaticecotoxicity	Volume of water polluted by product (“EcotoxAq”)	m^3/ product
		Production of ultimatewaste	Mass of ultimate waste generated by product (“WasteU”)	kg/ product

2.2.2.2Calculation method of Environmental impacts for transports and tasks

For a given process (transport mode or task), environmental impacts are calculated using Formula (4):

$$IEPR = IEE + IEPE \times QPE \quad (4)$$

Where
IEPR = Impact per unit of process;
IEE = Impact of combustion of energy source per unit of process;
IEPE = Impact related to production of one unit of energy source (fuel,electricity, etc.);
QPE = Number of units of energy source (fuel, electricity, etc.) consumed by one unit of process.

2.2.2.3Calculation method of environmental impacts for raw materials

For a raw material on construction site, environmental impacts are calculated using Formula (5):

$$IEM = IEM_0 + QM \times \sum_{i=1}^{i=m} (IET_i \times DT_i) \quad (5)$$

Where
IEM = Impact per unit of raw material on site;
IEM_0 = Impact of production of one unit of raw material;
QM = Mass of one unit of raw material;
IET_i = Impact per unit of transport mode no. i per unit of mass and per unit of distance;
DT_i = Average distance traveled by transport mode no. i during transportation process from production point to construction site;
m = Number of transport modes used to move raw material.

2.2.2.4Calculation method of environmental impacts for construction products

If a product is manufactured outside construction site, then its environmental impact is computed using Formula (6):

$$IEP = IEP_0 + QP \times \sum_{i=1}^{i=m}(IET_i \times DT_i) + \sum_{j=1}^{j=n} IETA_j \quad (6)$$

Where
IEP = Impact per unit of product;
IEP_0 = Impact of one unit of product at production point;
QP = Mass of one unit of product;
IET_i = Impact per unit of transport mode no. i per unit of mass and per unit of distance;
DT_i = Average distance traveled by transport mode no. i during transportation process from production point to construction site;
m = Number of transport modes used to move product.
$IETA_j$ = Impact of task no. j for integration of one unit of product into a building;
n = Number of required tasks.

If a product is manufactured inside construction site, then its environmental impact is computed using Formula (7):

$$IEP = \sum_{i=1}^{i=m} IEM_i \times QM_i + \sum_{j=1}^{j=n} IETA_j \quad (7)$$

Where
IEP = Environmental impact per unit of product;
IEM_i = Environmental impact per unit of raw material no. i on site;
QM_i = Number of unit of raw material no. i within one product unit;
m = Number of raw materials making up the product;
$IETA_j$ = Impact of task no. j for production of one unit of product or for its integration into a building;
n = Number of required tasks.

2.2.3Sources for data collection

For collecting data on construction products in Cameroonian context, we make use of:

1- Research work carried out by Laboratory of Civil and Mechanical Engineering of National Advanced School of Engineering of Yaounde (NASE/UYI);
2- Joint work of Civil Engineering Department of NASE/UYI and stakeholders of AEC industry in Cameroon (design offices, hardware stores, Ministry of Public Works, etc.);
3- Online databases and scientific publications related to environmental impacts.

Table III, which provides cost and environmental impacts of some products and processes in Cameroon, results of our computations using data from Elime (2012), Mamba (2013a, 2,013b, 2013c), Dones et al., (2007), Spielmann et al. (2007), Inies (2019) and Formulas (1) to (7).

Table III. **Cost and environmental impacts for some construction products and processes**

	Reinforced concrete beams (C20/25)	**Steelbeams**	**Excavation of loosematerials**	**Woodenform work**	**Road transport**
Unit	m^3	m^3	m^3	m^2	T.km
Cost (FCFA/ Unit)	109 076	4 917 220	1 600	3 500	15
Energyconsumption (MJ/ Unit)	5.65×10^{3}	3.93×10^{5}	3.12×10^{1}	6.25×10^{2}	2.22×10^{0}
Water consumption (L/ Unit)	3.08×10^{3}	1.70×10^{5}	2.65×10^{0}	1.56×10^{0}	1.89×10^{-1}
Production of ultimate waste (kg/ Unit)	1.03×10^{3}	5.54×10^{2}	1.53×10^{-3}	0.00×10^{0}	1.09×10^{-4}
Contribution to global warming (kg eq-CO_2/ Unit)	6.34×10^{2}	3.26×10^{4}	1.17×10^{0}	5.44×10^{1}	8.31×10^{-2}
Atmospheric acidification (kg eq-SO_2/ Unit)	2.14×10^{0}	1.34×10^{2}	7.08×10^{-3}	4.94×10^{-2}	5.05×10^{-4}
Eutrophization (kg eq-PO_4^{3-}/ Unit)	2.14×10^{-1}	1.19×10^{1}	1.43×10^{-3}	8.13×10^{-3}	1.02×10^{-4}
Aquaticecotoxicity (m^3/ Unit)	1.02×10^{1}	9.78×10^{2}	1.18×10^{-5}	6.25×10^{-4}	8.43×10^{-7}
Photochemical ozone formation (kg eq-C_2H_4/ Unit)	2.07×10^{-1}	1.60×10^{1}	6.57×10^{-6}	1.13×10^{-2}	4.68×10^{-7}

2.3Methodology for description of structure of objects

2.3.1Classification of objects

Using principles of ISO 12006 standard, we have defined four levels to classify our objects:
1- At level 1, objects are classified in structural work and non-structural work;
2- At level 2, objects of level 1 are subdivided according to their function (shallow foundation, deep foundation, wall, beam, slab, frame,… for objects of structural works);
3- At level 3, objects of level 2 are classified according to their geometrical or spatial specificities (prismatic, cylindrical, axisymmetric, etc. for example);
4- At level 4, objects of level 3 are subdivided according to their constitutive material (concrete, reinforced concrete, steel, wood, stabilized earth, terracotta, etc.).

This classification system, applied to objects commonly used for building projects in Cameroon, has led to results presented in Figure 2.

2.3.2Data structure of objects

We defined data structure of objects using principles of ISO 12006 standard.

The name of an object will have the following structure:
Id_DenominationMaterial_Dimension1×Dimension2×…×DimensionN

For a given object, data will be organized in attributes as shown in Table IV below.

For a given object, cost price is calculated using Formula (8):

$$CRO = \sum_{i=1}^{i=m} CP_i \times QP_i + \sum_{j=1}^{j=n} CTA_j \quad (8)$$

Where
CRO = Cost price of object;
CP_i = Cost of one unit of product no. i used to make up object;
QP_i = Number of units of product no. i within object;
m = Number of products making up object;
CTA_j = Cost of task no. j used to make up object;
n = Number of required tasks.

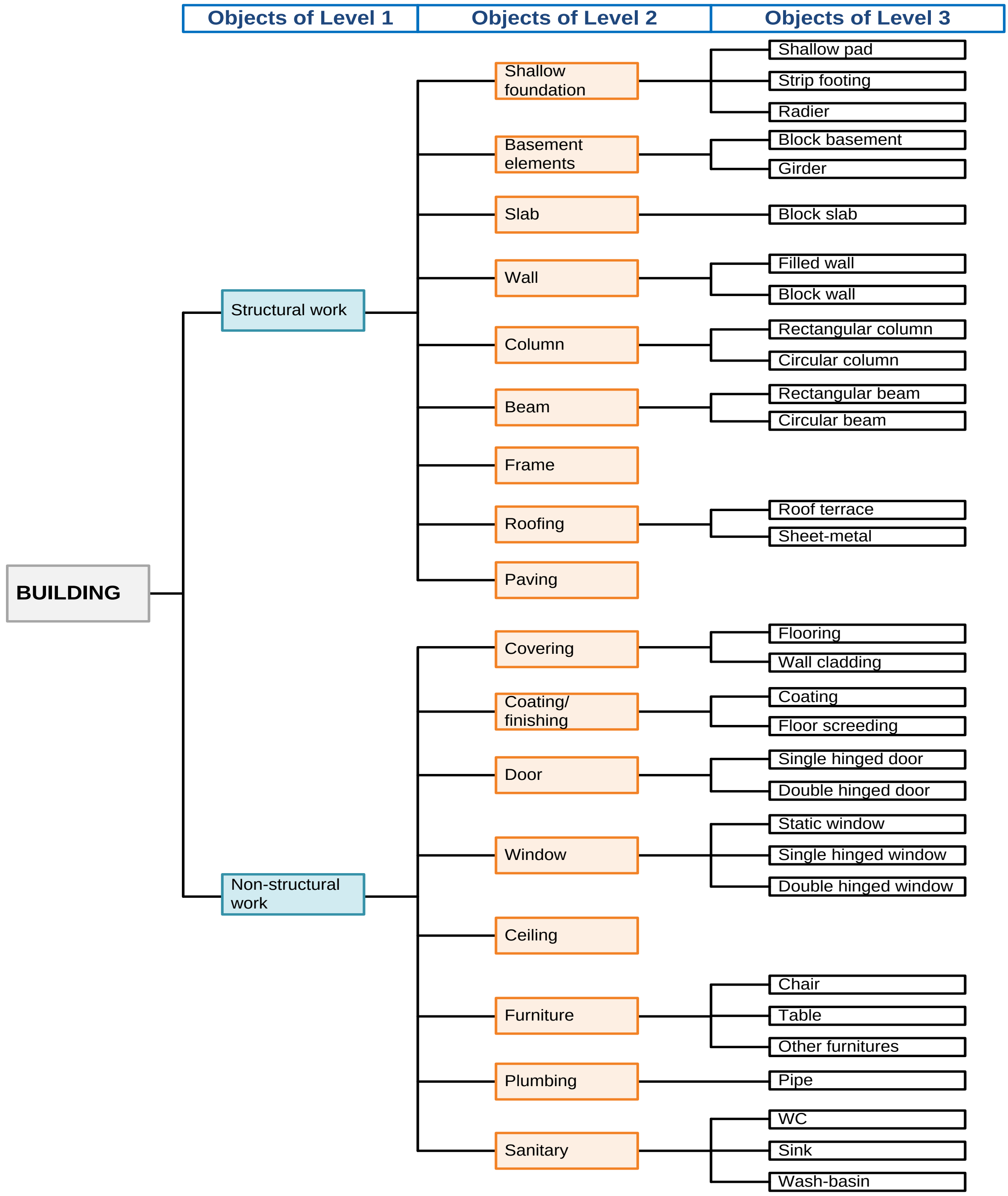

Figure 2:Classification of objects commonly used for building construction in Cameroon

We evaluate cost of selling an object with simplified Formula (9) from Mamba (2013c).

$$CVO = 3.CRO \tag{9}$$

Where

CVO = Selling cost of object;

CRO = Cost price of object.

Environmental impacts related to production of an object are computed using Formula (10):

$$IEO = \sum_{i=1}^{i=m} IEP_i \times QP_i + \sum_{j=1}^{j=n} IETA_j \quad (10)$$

Where

IEO	=	Environmental impact of object
IEP_i	=	Environmental impact of one unit of product no. i used to make up object;
QP_i	=	Number of units of product no. i within object;
m	=	Number of products making up object;
$IETA_j$	=	Environmental impact of task no. j used to make up object;
n	=	Number of required tasks.

Table IV. **General data structure of an object**

Categoriesofattributes	**Objectattributes**	**Unit**	**Data type**	**Comment**
Constitutive material	$Mater_k$	-	Text	Constitutive material no. k (k an integer from 1 to n, n ≥ 1)
	$VarMater_k$	-	Text	Subfamily of constitutive material $Mater_k$
	$MV\_VarMater_k$	T/m^3	Number	Unit mass of $VarMater_k$
	$E\_VarMater_k$	MPa	Number	Young modulus$VarMater_k$
	$RC\_VarMater_k$	MPa	Number	Compressivestrengthof$VarMater_k$
	$RT\_VarMater_k$	MPa	Number	Tensilestrengthof$VarMater_k$
	CT_k	W/ m.°C	Number	Thermal conductivityof$VarMater_k$
	$DR\_Element_p$	km	Number	Average distance traveled to move an element (raw material or product) no. p (p an integer from 1 to m, m ≥ 1) from a given point to construction site, by road
	$DF\_Element_p$	km	Number	Average distance traveled to move an element (raw material or product) no. p (p an integer from 1 to m, m ≥ 1) from a given point to construction site, by railway
General description	Unit	-	Text	Unit ofobject
	Mass	T	Number	Mass of one unit of object
	DDV	Year	Number	Lifetimeofobject
Geometry	$Dimension_j$	m	Number	Dimension no. j (j an integer from 2 to s, s ≥ 2) related to geometry of object
	Surface	m^2	Number	A surface related to one unit of object
	Volume	m^3	Number	Volume of one unit of object
Cost	CostPrice	FCFA	Number	Cost price or cost related to material, workforce, equipment used to made up object (Formula (8))
	CostSelling	FCFA	Number	Selling cost of object (Formula (9))
Environmental performance	Energy	MJ	Number	Energy consumption related to production of one unit of object (Formula (10))
	Water	L	Number	Water consumption related to production of one unit of object (Formula (10))
	WasteU	kg	Number	Ultimate waste generation related to production of one unit of object (Formula (10))
	GWP	kg eq-CO_2	Number	Contribution to global warming related to production of one unit of object (Formula (10))
	Acidification	kg eq-SO_2	Number	Acidification related to production of one unit of object (Formula (10))
	Eutrophization	kg eq-PO_4^{3-}	Number	Eutrophization related to production of one unit of object (Formula (10))
	EcotoxAq	m^3	Number	Aquatic ecotoxicity related to production of one unit of object (Formula (10))
	Smog	kg eq-C_2H_4	Number	Photochemical ozone formation related to production of one unit of object (Formula (10))

For illustration purpose, in Table V, we present data structure of the object "01_PoutreRectangulaireBA C20-25_20x30" that we have developed and which represents a rectangular reinforced concrete beam based on class C 20/25 concrete and of 20 cm × 30 cm section.

Table V. **Data structure of the object "01_RectangularBA C20-25_20x30"**

Categoriesofattributes	**Objectattributes**	**Unit**	**Value/ Expression**
Constitutive material	Mater$_1$	-	Concrete
	VarMater$_1$	-	C20/25
	MV_VarMater$_1$	T/ m^3	2.3
	E_VarMater$_1$	MPa	30 000
	RC_VarMater$_1$	MPa	20
	RT_VarMater$_1$	MPa	1.8
	CT_VarMater$_1$	W/ m.°C	0.22
	Mater$_2$	-	Steel
	VarMater$_2$	-	Steel1
	MV_VarMater$_2$	T/ m^3	7.7
	E_VarMater$_2$	MPa	210 000
	RC_VarMater$_2$	MPa	400
	RT_VarMater$_2$	MPa	400
	CT_VarMater$_2$	W/ m.°C	45
	DR_Steel	km	-(*)
	DR_Cement	km	-(*)
	DR_Sand	km	-(*)
	DR_Gravel5/15	km	-(*)
	DR_Gravel15/25	km	-(*)
	DF_Steel	km	-(*)
	DF_Cement	km	-(*)
	DF_Sand	km	-(*)
	DF_Gravel5/15	km	-(*)
	DF_Gravel15/25	km	-(*)
General description	Unit	-	Beam
	Mass	T	MV_VarMater$_1$×Volume×(1-0.08/ MV_VarMater$_2$) +0.08×10^{-3}×Volume/MV_VarMater$_2$
	DDV	Year	50
Geometry	Height	m	0.30
	Width	m	0.20
	Span	m	-(*)
	Surface	m^2	Height×Width
	Volume	m^3	Span×Surface
Cost	CostPrice	FCFA	109 076 +3 500× Span×(2Height+Width) +30×(0.08DR_Steel +0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume +15×(0.08DR_Steel +0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	CostSelling	FCFA	3×CostPrice

(*)Data to be defined by engineers during design process.

Categoriesofattributes	Objectattributes	Unit	Value/ Expression
Environmental performance	Energy	MJ	5.65×10^3 $+6.25\times10^2\times$Span$\times$(2Height+Width) $+2.22\times10^0\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+1.13\times10^0\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	Water	L	3.08×10^3 $+1.56\times10^0\times$Span$\times$(2Height+Width) $+1.89\times10^{-1}\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+6.80\times10^{-2}\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	WasteU	kg	1.03×10^3 $+0.00\times10^0\times$Span$\times$(2Height+Width) $+1.09\times10^{-4}\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+4.89\times10^{-4}\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	GWP	kg eq-CO_2	6.34×10^2 $+5.44\times10^1\times$Span$\times$(2Height+Width) $+8.31\times10^{-2}\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+5.18\times10^{-2}\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	Acidification	kg eq-SO_2	2.14×10^0 $+4.94\times10^{-2}\times$Span$\times$(2Height+Width) $+5.05\times10^{-4}\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+4.69\times10^{-4}\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	Eutrophization	kg eq-PO_4^{3-}	2.14×10^{-1} $+8.13\times10^{-3}\times$Span$\times$(2Height+Width) $+1.02\times10^{-4}\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+1.09\times10^{-4}\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	EcotoxAq	m^3	1.02×10^1 $+6.25\times10^{-4}\times$Span$\times$(2Height+Width) $+8.43\times10^{-7}\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+1.86\times10^{-8}\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume
	Smog	kg eq-C_2H_4	2.07×10^{-1} $+1.13\times10^{-2}\times$Span$\times$(2Height+Width) $+4.68\times10^{-7}\times$(0.08DR_Steel+ 0.34DR_Cement +0.66DR_Sand +0.21DR_Gravel5/15 +0.91DR_Gravel15/25) ×Volume $+7.59\times10^{-7}\times$(0.08DF_Steel+ 0.34DF_Cement +0.66DF_Sand +0.21DF_Gravel5/15 +0.91DF_Gravel15/25) ×Volume

(*) Data to be defined by engineers during design process.

2.4Methodology for description of structure of objects

We have implemented thirty BIM objects (beams, columns, foundations, frames, etc.) in ".RFA" format using Revit 2018 platform. This implementation has three main steps described in Figure 3, namely:

1- Creation of library of construction materials;
2- Creation of shared parameters file integrating cost and environmental impacts;
3- Creation of BIM objects at LOD 300.

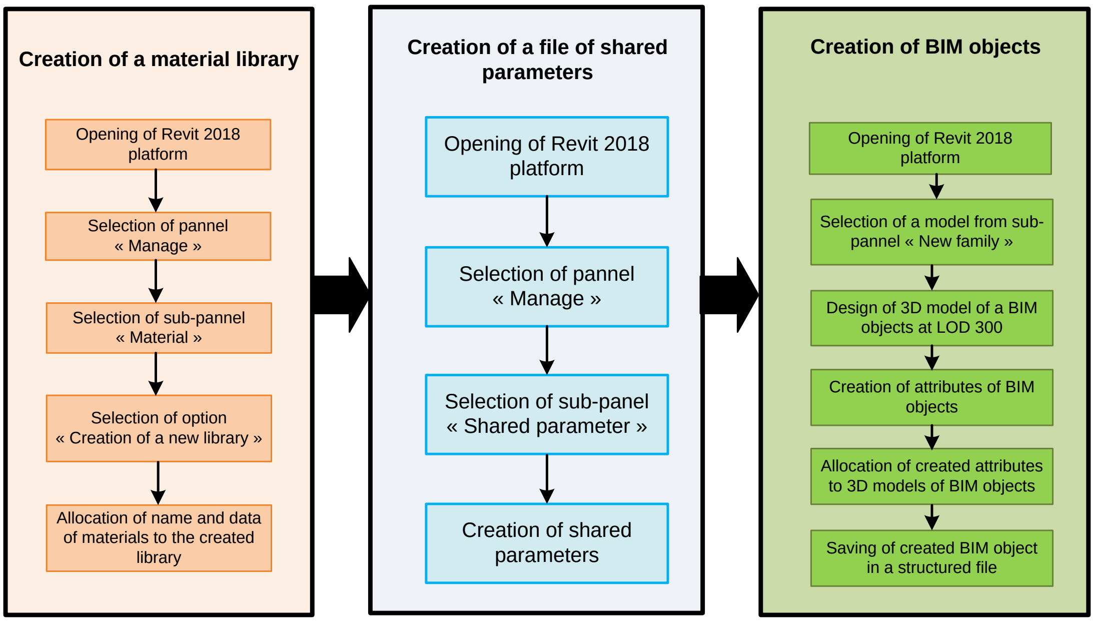

Figure 3:Methodology for implementation of BIM objects

In Figure 4, we present results of implementation of object "01_RectangularBA C20-25_20x30" on Revit 2018 platform. Attributes presented in Table V have been used for this purpose.

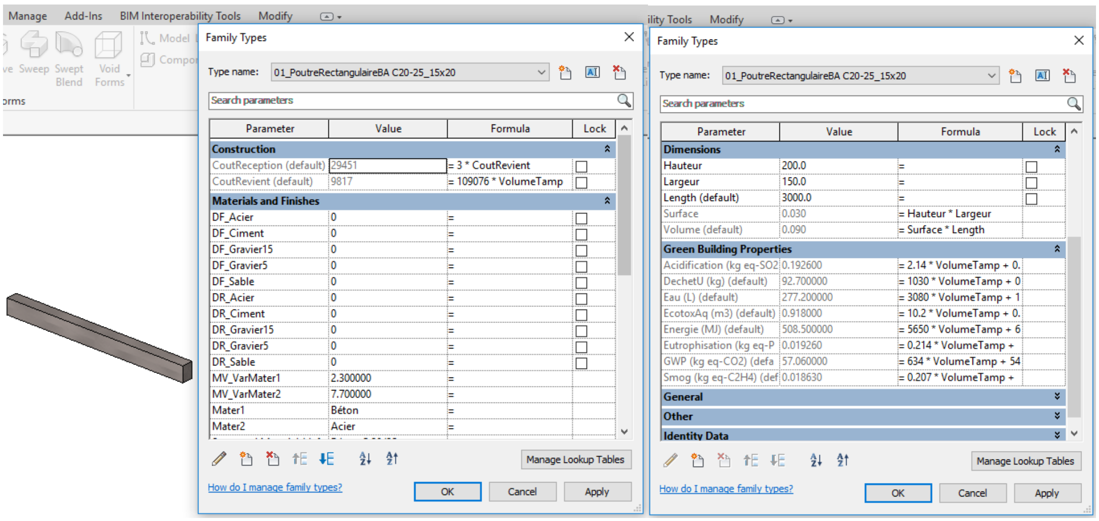

Figure 4:Results of implementation of BIM object "01_PoutreRectangulaireBA C20-25_20x30"

III. CASE STUDY

3.1Presentation of the construction project

A classroom for 40 students, with a gross area of 101 m^2 and located in Yaounde (Cameroon), has been designed using Revit 2018 platform and implemented BIM objects, in order to evaluate: amount of required materials, financial and environmental impacts related to the classroom construction.

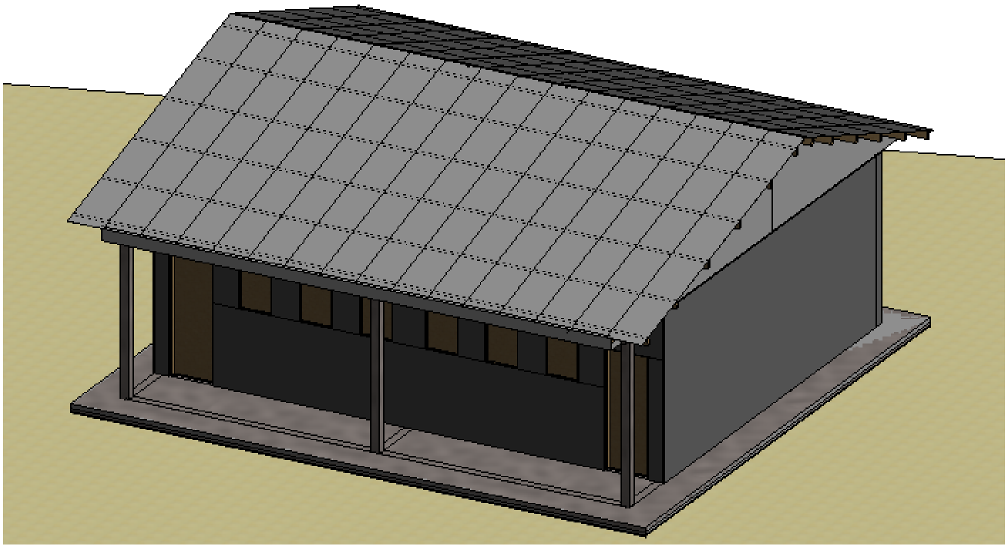

Figure 5:Perspective view of the classroom

Architecture of the studied classroom architecture is depicted by Figures 6 to 8. The building is 10.50m long, 9.65m wide, and 4.91m high.

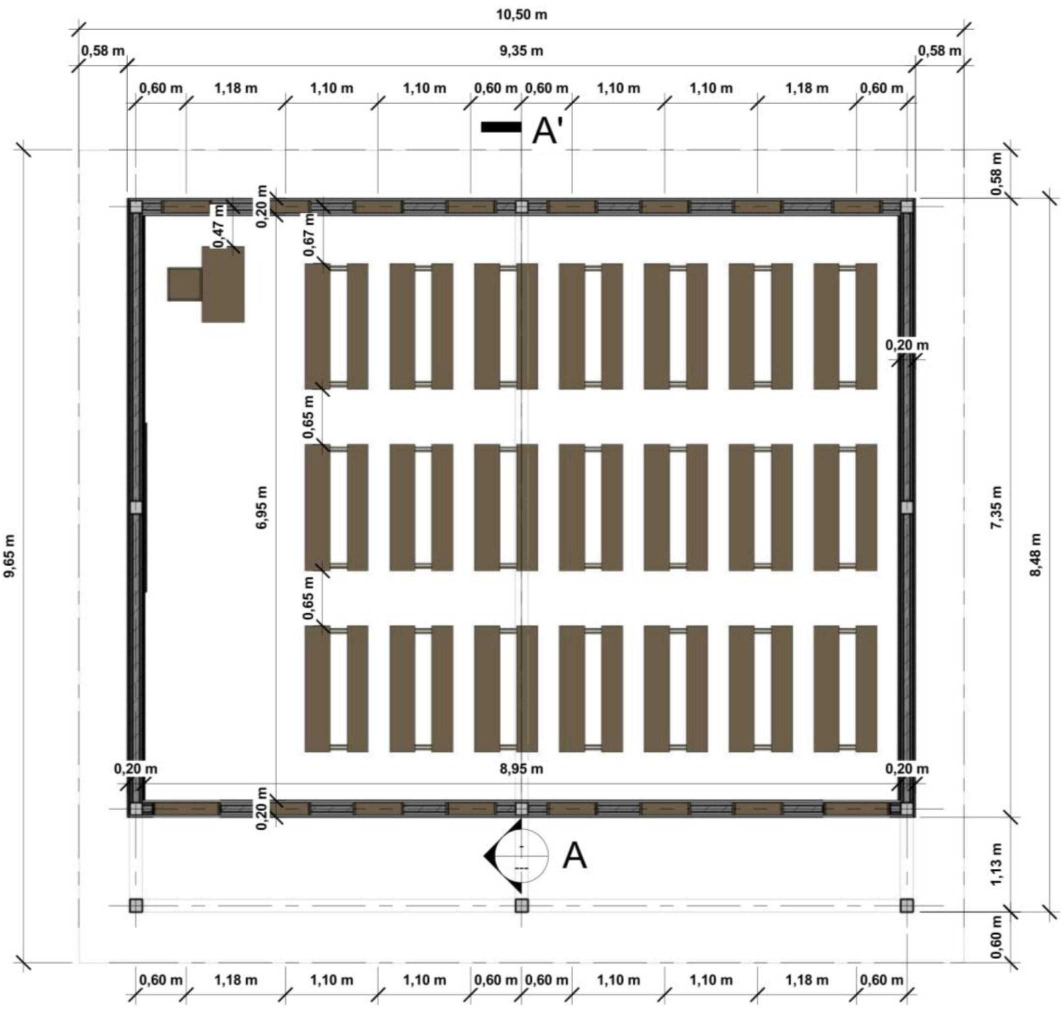

Figure 6:Plan view of the classroom

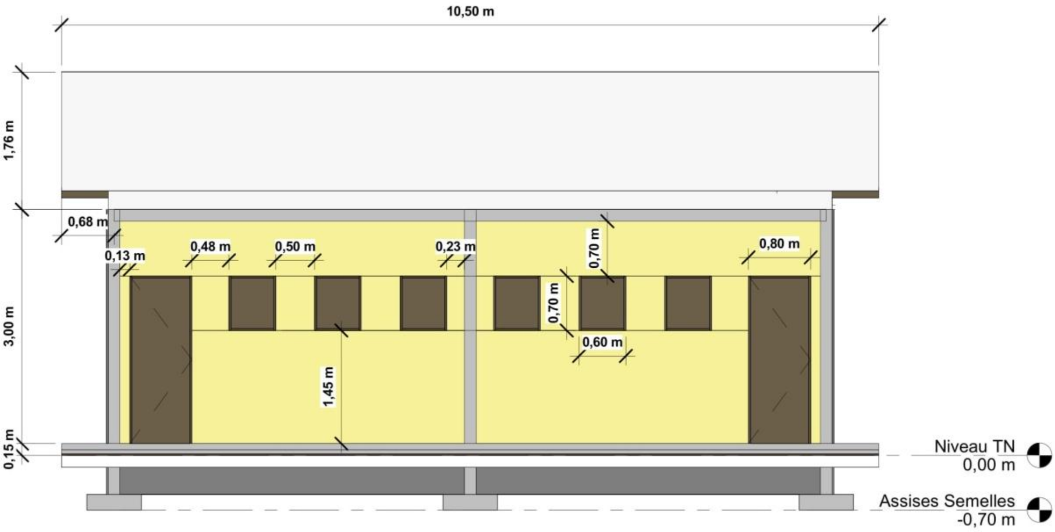

Figure 7:Main facade of the classroom

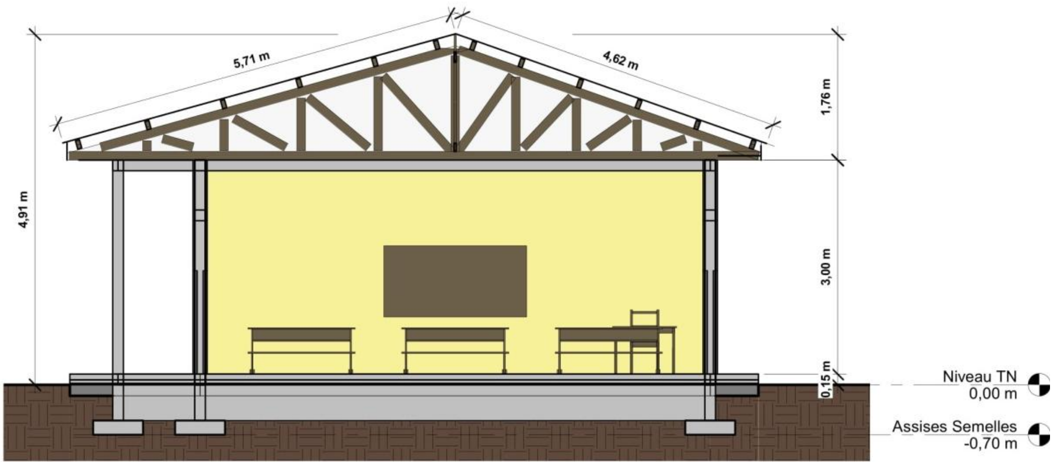

Figure 8:Section A-A ’of the classroom

Materials required for the classroom construction are specified in Table VI. These materials are transported and corresponding paths are shown in Figure 9.

***Table VI.* Construction products and materials required for the classroom construction**

N°	Parts oftheclassroom	Constructionproducts	Materials
1	Foundation	Shallow reinforced concrete pad	Concrete C 20/ 25, steel for reinforcement
		Core-filled concrete blocks of 20 cm	Motar M 8/ 10
		Reinforcedconcrete beam	Concrete C 20/ 25, steel for reinforcement
		(Cement) mortarjointof 1 cm	Mortar M 12/ 15
		Reinforcedconcretepaving	Concrete C 20/ 25, steel for reinforcement, filling
2	Beams	Reinforcedconcrete beam	Concrete C 20/ 25, steel for reinforcement
3	Columns	Reinforcedconcretecolumn	Concrete C 20/ 25, steel for reinforcement
4	Walls	Concreteblocksof 15 cm	Mortar M 8/ 10
		(Cement) mortarjointof 1 cm	Mortar M 12/ 15
5	Coating/ finishing	Cementmortarcoating	Mortar M 16/ 20
		Finishing	Paint
6	Doors	Woodendoor	Iroko
7	Windows	Woodenwindow	Iroko
8	Frame	Triangularwoodenframe	Iroko
9	Covering	Aluminium sheet of 8/10 mm thickness	Aluminium

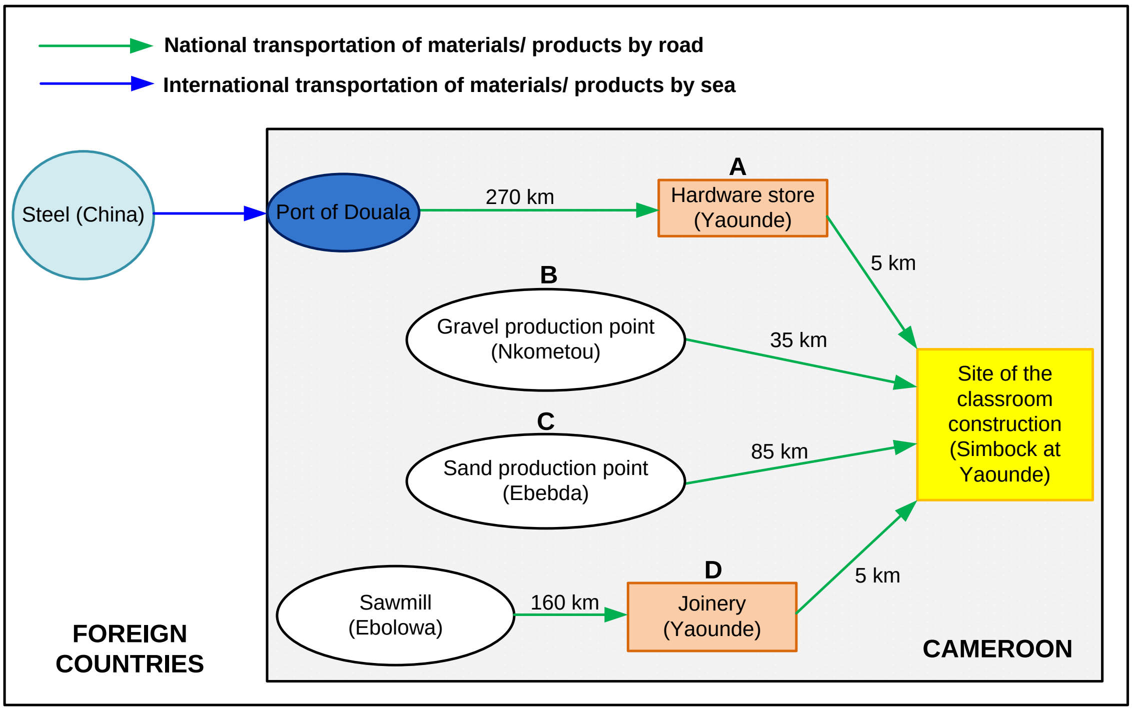

Figure 9:System boundaries for the classroom construction

3.2Obtained results

3.2.1Material required for the classroom construction

Using Revit 2018 platform and information in shared parameters of BIM objects, it is possible to generate automatically amount of required materials according to objects that make up the classroom (Figure 10). Obtained results are summarized in Table VII. It appears that construction of the classroom requires: 1.028 tons of steel, 20.645 m^3 of cement concrete, 12.354 m^3 of cement mortar, 5.854 m^3 of wood, 149 m^2 of aluminium sheets and 177 m^2 of paint (Table VII).

A	B	C	D	E	F
Famille d'objets	Familles et Objets	Acier pour armatures (T)	Bois (m3)	Béton de ciment C 20/25 (m3)	Béton de propreté (m3)
Bardage					
Bardage	Bardage: 01_TôleAluminium_0.8				
Bardage	Bardage: 01_TôleAluminium_0.8				
Bardage	Bardage: 01_TôleAluminium_0.8				
Bardage	Bardage: 01_TôleAluminium_0.8				
Bardage	Bardage: 01_CouvreJointAluminium_0.8				
Bardage	Bardage: 01_CouvreJointAluminium_0.8				
Bardage		0	0	0	0
ChaiseBois					
ChaiseBois	ChaiseBois: 01_ChaiseBois_90		0,007334		
ChaiseBois		0	0,007334	0	0
DallageBA					
DallageBA	DallageBA: 01_DallageBA C20-25	0,64848		8,021782	5,06625
DallageBA		0,64848	0	8,021782	5,06625
Eléments de la ferme en bois					
Eléments de la ferme en bois	Eléments de la ferme en bois: 6x12		0,06948		
Eléments de la ferme en bois	Eléments de la ferme en bois: 6x12		0,040352		
Eléments de la ferme en bois	Eléments de la ferme en bois: 6x12		0,03245		
Eléments de la ferme en bois	Eléments de la ferme en bois: 3x12		0,0054		
Tôle					
Tôle	Tôle: 01_PlafonAluminium_0.8				
Tôle	Tôle: 01_TôleAluminium_0.8				
Tôle	Tôle: 01_TôleAluminium_0.8				
Tôle	Tôle: 01_PlafonAluminium_0.8				
Tôle		0	0	0	0
Total général		1,02839	5,853615	12,721318	7,923672

Figure 10:Outline of required materials for the classroom construction (from Revit 2018 platform)

***Table VII.* Required materials for the classroom construction**

N°	Objects	Steel (T)	Wood (m^3)	Concrete (m^3)	Mortar (m^3)	Paint (m^2)	Filling (m^3)	Aluminium Sheet (m^2)
1	Boarding	0	0	0	0	0	0	21
2	Chair	0	0.007	0	0	0	0	0
3	Covering	0	0	0	0	0	0	129
4	Paving	0.648	0	13.088	0	0	2.027	0
5	Coating/ finishing	0	0	0	4.414	177	0	0
6	Window	0	0.074	0	0	0	0	0
7	Frame	0	0.612	0	0	0	0	0
8	Girder	0.094	0	1.166	0	0	0	0
9	Block wall	0	0	0	5.772	0	0	0
10	Purlinsandtierods	0	0.976	0	0	0	0	0
11	Ceiling	0	3.098	0	0	0	0	0
12	Door	0	0.118	0	0	0	0	0
13	Column	0.072	0	0.894	0	0	0	0
14	Beam	0.127	0	1.573	0	0	0	0
15	Shallow pad	0.086	0	1.067	0	0	0	0
16	Filled block basement	0	0	2.857	2.168	0	0	0
17	Blackboard	0	0.05	0	0	0	0	0
18	Table forteacher	0	0.015	0	0	0	0	0
19	Table forstudent	0	0.905	0	0	0	0	0
	Classroom	**1.028**	**5.854**	**20.645**	**12.354**	**177**	**2.027**	**149**

3.2.2Financial and environmental impacts of the classroom construction

Using Revit 2018 platform and information in shared parameters of BIM objects, it is possible to generate automatically Figure 11 which provides financial and environmental impacts according to objects making up the classroom. Obtained results are summarized in Table VIII and Figure 12. It appears that the classroom construction project costs 13 545 450 FCFA and generates 20.2 tons of CO_2 and 29.7 tons of ultimate waste. In addition, this process consumes 195.7 GJ of energy and 69.2 m^3 of water (Table VIII).

A	B	C	D	E	F	G
Famille d'objets	Familles et Objets	Coût de Vente (FCFA)	Acidification (kg eq-SO2)	DechetU (kg)	Energie (MJ)	Eau (L)
Bardage						
Bardage	Bardage: 01_TôleAluminium_0.8	39786	0,016086	0,065943	234,697022	6,018398
Bardage	Bardage: 01_TôleAluminium_0.8	50421	0,020386	0,083571	297,43781	7,627277
Bardage	Bardage: 01_TôleAluminium_0.8	50421	0,020386	0,083571	297,43781	7,627277
Bardage	Bardage: 01_TôleAluminium_0.8	39828	0,016103	0,066015	234,955214	6,025019
Bardage	Bardage: 01_CouvreJointAluminium_0.8	25392	0,010266	0,042085	149,785744	3,840996
Bardage	Bardage: 01_CouvreJointAluminium_0.8	20313	0,008213	0,033668	119,828595	3,072797
Bardage: 6		226161	0,091439	0,374853	1334,142195	34,211764
ChaiseBois						
ChaiseBois	ChaiseBois: 01_ChaiseBois_90	6549	0,002969	0,000003	37,602181	0,098311
ChaiseBois: 1		6549	0,002969	0,000003	37,602181	0,098311
DallageBA						
DallageBA	DallageBA: 01_DallageBA C20-25	3403545	20,124385	11758,916335	53359,400651	29583,696407
DallageBA: 1		3403545	20,124385	11758,916335	53359,400651	29583,696407
Eléments de la ferme en bois						
Eléments de la ferme en bois	Eléments de la ferme en bois: 6x12	47079	0,028182	0,000024	356,231186	0,931366
Eléments de la ferme en bois	Eléments de la ferme en bois: 6x12	27342	0,016367	0,000014	206,889567	0,540912
Eléments de la ferme en bois	Eléments de la ferme en bois: 6x12	21987	0,013162	0,000011	166,374327	0,434985
Tôle						
Tôle	Tôle: 01_PlafonAluminium_0.8	159882	0,064642	0,265001	943,167009	24,185883
Tôle	Tôle: 01_TôleAluminium_0.8	655287	0,264939	1,08612	3865,612562	99,126934
Tôle	Tôle: 01_TôleAluminium_0.8	529776	0,214194	0,878088	3125,207076	80,140519
Tôle	Tôle: 01_PlafonAluminium_0.8	59955	0,024241	0,099375	353,687628	9,069706
Tôle: 4		1404900	0,568016	2,328584	8287,674274	212,523042
Total général: 260		13545450	51,714326	29722,577885	195737,761562	69239,495323

Figure 11:Outline of financial and environmental impacts for the classroom construction (from Revit 2018 platform)

***Table VIII.* Financial and environmental impacts of the classroom construction**

N°	**Impacts of the classroom construction (Unit)**	**Impact values**	**Impact values per m^2 of gross area**
1	Sellingcost (FCFA)	13 545 450	133 683
2	Atmospheric acidification (kg eq-SO_2)	51.714	0.510
3	Production of ultimate waste (kg)	29 722.600	293.339
4	Energyconsumption (MJ)	195 738.000	1 931.784
5	Waterconsumption (L)	69 239.500	683.341
6	Eutrophization (kg eq-PO_4^{3-})	6.251	0.062
7	Aquaticecotoxicity (m^3)	1 967.287	19.416
8	Contribution to global warming (kg eq-CO_2)	20 231.246	199.667
9	Photochemicalozone formation (kg eq-C_2H_4)	17.758	0.175

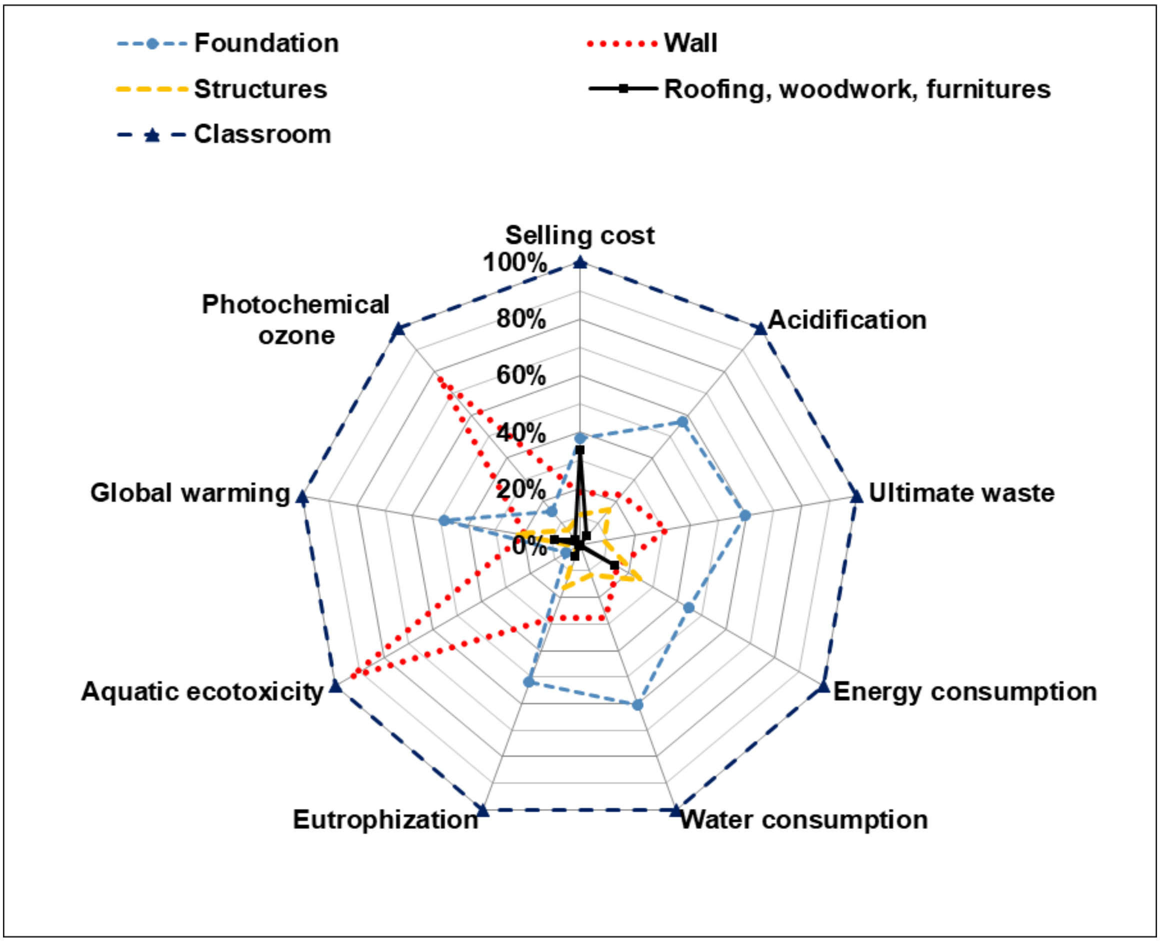

Figure 12:Financial and environmental impacts by group of objects for the classroom construction

3.3Discussion of results

Table IX compares financial and environmental impacts for the classroom construction resulting from: Revit 2018 platform, by exploiting the BIM objects created (Table VI); manual computations using amount of required materials (Table VII), transport distances (Figure 9), classroom architecture (Figures 5 to 8), cost and impacts of products and processes (Table III), Formulas (8) to (10). It shows that, for the classroom construction process, BIM objects and Revit platform allow to evaluate financial and environmental impacts with a maximum deviation of 0.3% compared to manual computations.

***Table IX.* Deviations between impacts provided by Revit 2018 platform and impacts computed manually**

N°	Impacts of the classroom construction (Unit)	Impact values per m^2 gross area provided by Revit 2018 platform	Impact values per m^2 gross area computed manually	Deviations
1	Sellingcost (FCFA)	133 683	133 772	-0.07%
2	Atmospheric acidification (kg eq-SO_2)	0.510	0.511	-0.04%
3	Production of ultimate waste (kg)	293.339	293.607	-0.10%
4	Energyconsumption (MJ)	1 931.784	1 932.397	-0.05%
5	Waterconsumption (L)	683.341	683.835	-0.07%
6	Eutrophization (kg eq-PO_4^{3-})	0.062	0.062	-0.02%
7	Aquaticecotoxicity (m^3)	19.416	19.463	-0.26%
8	Contribution to global warming (kg eq-CO_2)	199.667	199.763	-0.05%
9	Photochemical ozone formation (kg eq-C_2H_4)	0.175	0.176	-0.20%

IV. CONCLUSION

In a context where spreading of BIM in sub-Saharan Africa requires a strong involvement of institutions dedicated to training and research in civil engineering, this article propose an approach to automatically evaluate cost and environmental impacts of buildings construction in Cameroon. Based on integration of cost and environmental data within BIM objects, this approach has been implemented for building construction projects in Cameroon. It has led to creation of a library of LOD 300 BIM objects on Revit 2018 platform.

The use of this BIM object library on Revit 2018 platform to design a classroom in Yaounde make it possible to generate automatically cost and environmental impacts of the classroom construction with a maximum deviation of 0.3% compared to manual computations. Obtained results open new perspectives for optimal design of sustainable buildings using BIM objects.

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