WORLD SUSTAINABLE BUILDING 2014 BARCELONA CONFERENCE

Sustainable Building: RESULTS
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CONFERENCE PROCEEDINGS
VOLUME 6

This the sixth of seven volumes of the Conference Proceedings for World SB14 Barcelona, which took place in Barcelona on the 28th, 29th and 30th October 2014.

The Conference was organised by GBCe (Green Building Council España), co-promoted by iiSBE, UNEP-SBCI, CIB and FIDIC, and counted on the participation of World GBC*.

This volume gathers papers presented in the poster sessions from the Conference area "Creating New Resources", presented at World SB14 Barcelona on day 2 of the Conference. All the papers in this volume were double blind peer reviewed by the Scientific Committee of World SB14 Barcelona.

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***iiSBE:** International Initiative for a Sustainable Built Enviroment
UNEP-SBCI: United Nations Environment Programme - Sustainable Buildings and Climate Initiative
CIB: Conseil International de Batîment
FIDIC: International Federation of Consulting Engineers
World GBC: World Green Building Council

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Life Cycle Analysis of standard and high-performance cements based on carbon nanotubes composites for construction applications

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Abstract: *Research of new cement formulations is of outstanding interest for satisfying the new requirements in architectural and infrastructure projects safely, affordably and sustainably. Addition of nanofiber reinforcement to different matrices allows the crack growth control at nanoscopic scale, creating a whole new generation of crack-free materials. Among these new nano-reinforcements, the carbon nanotubes (CNTs) deserve to be highlighted considering that the addition of CNTs to cement leads to high-tech formula. Thus, high-performance cements based on carbon nanotube are being researched. However, the literature indicates considerable variability and uncertainty regarding the health impacts, reactivity, ecological effects, and environmental fate and transport of CNTs. Therefore, it is necessary to analysed how the addition of CNTs may affect the environmental profile of cement. This study evaluates hypothetical high-performance cements based on carbon nanotube reinforcement with a Life Cycle Assessment (LCA) in order to compare the environmental impact of these new developments with traditional cements. The results of the study indicate higher life cycle requirements and higher environmental impact of high-performance cements based on carbon nanotube composites as compare to tradicional ones.*

Keywords, Cement, CNT, Life Cycle Assessment

INTRODUCTION

It has been estimated that over 50% of the annual European construction budget is spent on the repair and refurbishment of existing structures, buildings and facilities [1]. Thus, the repair of deteriorating reinforced concrete structures is an inportant part of the global construction market. Moreover, the requirements in new architectural projects and civil infrastructure are more and more exigent. Therefore, new materials are needed for satisfying the new demands in a safe, affordable and efficient way.

At the beginning of the 21st century, the fast-emerging field of nanotechnology sparked a high level of interest from the scientific and industrial communities, and today, nanotechnology is being applied to almost every facet of modern life, and it is also revolutionizes the conventional construction materials: cement, concrete and wet mortar. In this way, for example, belonging carbon nanotubes (CNTs) to the new class of superior engineered materials because of their exceptional mechanical properties, Raki et al. reported that CNTs can improve the hardness of the early hydratation of the cement-based material by 600%, the Young modulus by 227% and the flexural strength by 40% [2]. Veedu incorporated 0,02 wt% CNTs into the cement-based materials to make its flexural and compressive strength increases by 30% and 100% [3]. However, it remains a significant lack of information regarding the health effects and environmental impacts of CNTs as well as how the addition of CNTs may affect the environmental profile of products. Given these uncertainties, it is of interest to carry

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out the Life Cycle Assessment (LCA) of these cements with CNTs to track the environmental impacts through their fabrication and to compare with those of the traditional cements. For developing the study, the life cycle inventory and the results of CNT´s assessments from the open literature have been used. Concretely, as carbon nanofibers have similar manufacturing methods with comparable impacts to CNTs [4], the results reported by Khanna for a cradle-to-gate LCA of vapor-grown carbon nanofibers habe been used [5].

METHODOLOGY

Environmental evaluation of the cements is carried out using a process-based life cycle assessment methodology with distinct stages to generate a comprehensive overview of the product´s total environmental effect: Goal and Scope definition, System Boundaries and Life Cycle Inventory and Data collection and Impact Assessment Method. This is a "cradle-to-gate" LCA that includes upstream inputs such as raw materials extraction and processing of the input materials and energy as well as the inputs and emissions associated with fabrication. LCA results have been obtained by using Simapro 8.0.1 software and CML-IA baseline v3.00 method.

LIFE CICLE ASSESSMENT

<u>Goal and Scope</u>

The goal of this study is to measure the environmental impact of hypothetical high-performance cements based on carbon nanotube reinforcement. Firstly, an ordinary Portland cement of the region (CEM I 52,5 N of FYM Italcementi Group, Añorga, Guipuzcoa, Spain) is evaluated. The functional unit is 1 t, since it is recommended in the appropiate Product Category Rules, PCR, according to ISO 14025:2006 [6].

<u>System Boundaries and Life Cycle Inventory</u>

The system used in this study is the production system of 1 t of CEM I, ordinary Portland cement. This type of cement is selected as it is composed with 93,5% by mass of clinker, primary reactive compound, which has the highest environmental impact due to kiln operation. Main processes of the system are: 1) extraction and crushing of raw materials, mostly obtained from their own quarries: limestone and calcareous marl; 2) clinker production, grinding of raw materials and running of kiln; 3) cement production, mixing and grinding with limestone and gypsum. The system finishes in factory's gate, when cement is ready for delivering, only considering storage in plant's silos.

Limestone quarry is 8 km away from the factory and calcareous marl quarry is next to it. Sand, gypsum and other additions quarries or providers are situated at maximum of 200 km from cement plant. Therefore, transport of raw materials is only done by freight lorry.

Primary fuel of clinker kiln is petroleum coque, although also municipal and tyre waste are burned, they can be considered as coque saving. Heavy fuel is only used to start the kiln after a technical or programmed stop.

After raw mill, blending and weighing processes take place. Clinker kiln is preceded by a preheater cyclone tower which helps saving fuel as raw materials do not enter completely cold. After kiln there is a grate cooler with bag filters and heat exchanger.

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CEM I Portland cement produced in Añorga (Spain) consists of 93,5% of clinker, 3,5% of gypsum and 3% of owned quarry's limestone. Complete life cycle inventory, LCI, of the cement production is showed in Table 1. All emission to water and air are also included in LCI table of clinker (Table 2).

Inputs	**Amount**
Clinker	0,935 t
Gypsum, mineral	0,035 t
Limestone, crushed	0,03 t
Cement factory	5,36E-11 p
Tap water	24,53 kg
Water, natural origin	0,925 m^3
Ethylene glycol	4,89E-04 kg
Steel, low-alloyed	0,116 kg
Electricity, high voltage, national mix	24 kWh
Outputs	
CEM I 52,5 N	1 t
Heat, waste	0,135 MJ
Water	0,804 m^3

Table 1: LCI of CEM I 52,5 N of Añorga's plant, FYM Italcementi Group

Inputs	**Amount**
Limestone, crushed	733,3 kg
Calcareous marl	254,6 kg
Sand	4,7 kg
Iron ore waste	7,4 kg
Petroleum coke	96,45 kg
Heavy fuel oil	1,73 kg
Municipal solid waste	1,065 kg
Inert waste, used tyres	17,44 kg
Refractory, fireclay	0,71 kg
Ammonia, liquid	3,75 kg
Cement factory	6,27E-12 p
Industrial machine	3,76E-05 kg
Lubricating oil	4,71E-05 kg
Steel, chromium steel 18/8, hot rolled	5,86E-05 kg
Electricity, high voltage, national mix	29,08 kWh
Emissions	**Amount (kg)**
Antimony	2E-09
Nitrogen oxides	1,03878944
Tin	9E-09
Zinc	7,6085E-05
Carbon dioxide, biogenic	0,01509999
Mercury	3,3E-08
Thallium	4,2952E-06
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	9,6E-13
NMVOC, non-methane volatile organic compounds	0,01367143
Methane, fossil	8,88E-06

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Copper	1,7184E-05
Cobalt	4E-09
Sulfur dioxide	0,09841769
Hydrogen chloride	0,00362583
Nickel	2,1833E-06
Arsenic	1,2E-08
Carbon dioxide, fossil	735,230754
Particulates, unspecified	0,06177276
Lead	9,6812E-06
Carbon monoxide, fossil	1,13869346
Vanadium	5E-09
Ammonia	0,00483087
Beryllium	3E-09
Chromium	1,4095E-05
Selenium	2E-09
Cadmium	7E-09
Manganese	1,0893E-05
Hydrogen fluoride	0,0009762
VOC, volatile organic compounds	0,00940606
Benzene	4,527E-05
Nitrogen monoxide	0
Anthracene	1,2058E-06
Naphthalene	4,042E-05
Hydrogen cyanide	0,00010445

Table 2: LCI of clinker produced in Añorga's plant, FYM Italcementi Group

Data collection and Impact Assessment Method

According to PCR, data concerning clinker and cement composition, as well as energy consumption, were kindly provided by the producer, manufacturing plant in Añorga, Spain. Likewise, data concerning transports, raw materials, fuels and atmospheric emissions were mostly provided by producer and normalized for the functional unit. Data concerning infrastructure are taken from Ecoinvent Database [7]. The producer has provided one year averaged data, from 2013 period. For the electricity used in cement factory, national electricity mix was obtained from 2013 monthly evaluation report of Red Eléctrica Española (Spanish Electric Net) [8]. Transport of raw materials is counted in terms of the capacity of the vehicle and the length of the routes travelled. Recycled waste used as alternative fuels is considered, in 2013 the clinker kiln burned 5405 tons of municipal and tyre waste.
According to PCR, environmental impact categories to consider in life cycle assessment are: Global Warming, Ozone Depletion, Acidification for soil and water, Eutrophication, Photochemical oxidation, Depletion of abiotic resources (for fossil fuels and for non-fossil resources.

CNF and CNT reinforcements LCA

The manufacturing cycle of CNF or CNT nanoproducts includes three stages: 1) raw material acquisition (depending on carbon source used), 2) synthesis and 3) purification. Raw materials needed are carbon precursor material (methane, ethylene or benzene considered as carbon sources); catalysts, solvent, hydrogen gas and sulphur sources for the reactor. There

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are four routes to synthetize CNTs, namely chemical vapour deposition, electric arc discharge, laser ablation and high pressure carbon monoxide process. For purification stage, there are also different techniques: air oxidation at high temperatures, refluxing with acids, sonication and annealing, and microwave-assisted purification. 1 kg of purified CNF or CNT is the functional unit for this cradle-to-gate life cycle assessment. The manufacturing stage is energy-intensive process; raw materials used in the reactor have associated high toxic emissions or waste; operation temperatures are very high. Threrefore, environmental impacts obtained will overcome traditional construction materials.
As considered by Upadhyayula et al. [4], CNF and CNT nanomaterials have similar manufacturing methods, data are obtained from a cradle-to-gate LCA reported by Khanna et al. [5] of a vapour-grown carbon nanofibers (VGCNFs). This method can provide of a continuous scale synthesis, which is appropriated for industrial products.
VGCNFs are produced by catalytic pyrolysis of hydrocarbons. A sulphur source is added to promote the formation of CNFs. As catalyst source, ferrocene ($C_{10}H_{10}Fe$) is dissolved in a suitable solvent (hexane). Temperature reaches 1100º-1200º C in the electric furnace. Hydrochloric acid is the acid used in purification stage. Total energy required for the process includes all stages: manufacturing and purification.
It has been considered that the amount of CNT is 0,75 wt% of dry cement, which is the needed amount to increase the flexural strength by about 88% [9].

RESULTS AND DISCUSSION

LCA results for the CEM I 52,5 N are presented in Table 3. Analysing the responsibility of each fabrication process for each impact category (Figure 1), it can be highlighted that clinker is 80% responsible of the impact in all of them, except for Terrestial ecotoxicity in which it is responsible for 55% of the environmental impact. In that category, high voltage electricity supplying is the second responsible of the impact.

Impact category	Unit	Amount
Abiotic depletion of resources	kg Sb eq	2,18E-04
Abiotic depletion of fossil fuels	MJ	1.484,5
Global warming, GWP	kg CO_2 eq	749
Ozone layer depletion, ODP	kg CFC-11 eq	7,58E-06
Human toxicity	kg 1,4-DB eq	66,584
Fresh water aquatic ecotox.	kg 1,4-DB eq	36,024
Marine aquatic ecotoxicity	kg 1,4-DB eq	100.751
Terrestrial ecotoxicity	kg 1,4-DB eq	0,827
Photochemical oxidation	kg C_2H_4 eq	0,056
Acidification	kg SO_2 eq	1,006
Eutrophication	kg PO_4^{2-} eq	0,222

Table 3: LCA results. Environmental impacts to produce 1 ton of cement CEM I 52,5 N.

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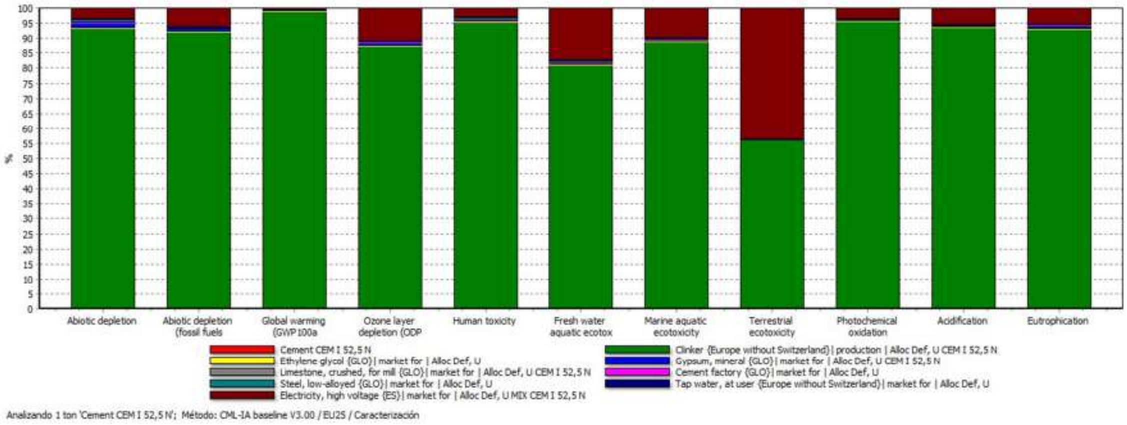

Figure 1: System boundaries and processes of the Añorga's cement plant.

In order to get a better insight in the environmental performance of the CEM I 52,5 N cement under study, a comparison with other similar LCA studies has been performed. The comparison has been performed on four environmental impact categories required by the cement Product Category Rules (CPC Class 3744 CEMENT, 2010:09), namely Global warming, Photochemical oxidation, Acidification and Eutrophication. Other environmental impact categories of the PCR (i.e. abiotic depletion impact categories and ozone depletion) have not been included because their calculation methodology differs between the different sources (e.g. aggregation of abiotic depletion indicators…). Main methodological points of LCA studies in the comparison are given in Table 4. From a general perspective, although some of these studies used different LCA methodological standards, the comparison is possible and relevant because all the presented LCA standards are based on the CML characterisation method [10]. Therefore, although some slight differences can be observed between the different versions of CML used in the different LCAs, the comparison is relevant. Figure 2 shows the results observed in these different LCA studies.

Study	**Product**	**Scope**	**Functional unit**	**LCA methodological standard**	**Geography**
Current study	CEM I 52,5 N	Cradle-to-gate	1 t	Cement PCR	Spain
ATILH, 2011	Portland CEM I 52,5 N et 52,5 R	Cradle-to-gate	1 t	NF P 01-010 (source)	France
ECOCEM, 2008	Portland cement (CEM I)	Cradle-to-gate	1 t	Cement PCR	Ireland
Nesher, 2014	CEM I 52,5 N	Cradle-to-gate	1 t	Cement PCR	Israel

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Table 4: Main methodological points of LCA studies used in the comparison.

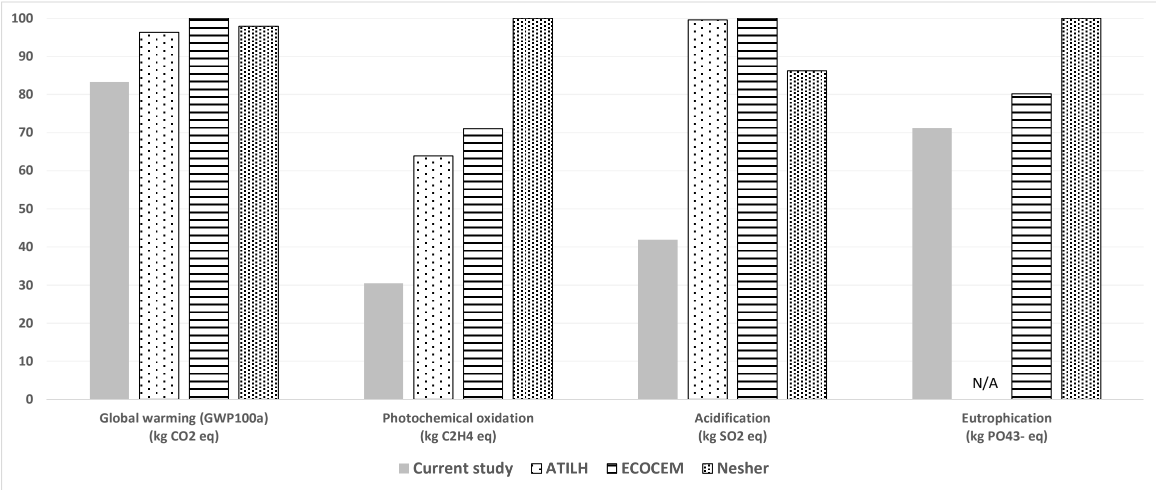

Figure 2: Comparison of LCA results with other similar LCA studies. For each impact category, the highest results is set to 100, other results are scaled accordingly.

As can be seen, the potential environmental impacts associated with the cement under study are lower than environmental impacts calculated in other LCA studies. This fact is attributed, on the one hand, to the lower distance of transportation of raw materials for the CEM I 52,5 N, and on the other hand, to the fossil fuel used for its fabrication.

In table 4 comparative impacts of the CEM I 52,5 N and reinforced cement are shown.

Impact category	Unit	1 kg CEM I 52,5 N	1 kg reinforced cement
Abiotic depletion of resources	kg Sb eq	2,184E-07	8,642E-06
Abiotic depletion of fossil fuels	MJ	1,485	56,719
Global warming, GWP	kg CO_2 eq	0,749	4,528
Ozone layer depletion, ODP	kg CFC-11 eq	7,588E-09	6,396E-07
Human toxicity	kg 1,4-DB eq	0,067	1,353
Fresh water aquatic ecotox.	kg 1,4-DB eq	0,036	3,384
Marine aquatic ecotoxicity	kg 1,4-DB eq	100,751	5985,378
Terrestrial ecotoxicity	kg 1,4-DB eq	0,00082736	0,18839807
Photochemical oxidation	kg C_2H_4 eq	5,5717E-05	0,00125085
Acidification	kg SO_2 eq	0,00100558	0,03213931
Eutrophication	kg PO^{2-}_4 eq	0,00022225	0,00745367

CONCLUSIONS

The major conclusion that we can draw is that the inclusion of CNTs increases considerably the environmental impact of cement production. Besides, progress in research on these kinds of systems is largely hampered by the intrinsically hydrophobic nature of CNTs and their chemical incompatibility with cement hydrates. Thus, we propose new alternatives to CNTs as reinforcement for cements such as inorganic nanotubes or plastic nanofibers.

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A Building Products Procurement Platform for Environmental Evaluation of Design Alternatives

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Abstract: *This work provides the basis for developing a building products procurement platform for environmental evaluation of design alternatives. The outcome is a ground for implementing existing tools and standards for life cycle assessment or environmental certification of buildings in the early building design stage.*

For this purpose, the first phase of the Life-cycle-support Building product Indexing Platform (Lcs-BIP) project is reported and demonstrated for a specific user case, procurement, through a workflow scheme. The federated solution introduced for environmental evaluation of design alternatives is composed of a web-based tool for life-cycle-support building procurement, coupled with a BIM-enabled platform and data sharing hub. The system assists users to maintain a trifold focus on competitive price, quality, and environmental performance of the building. The overall workflow of the system is explained through an exemplar scenario with the three disciplinary roles of an architect, a BIM administrator and a contractor.

Life cycle assessment, Building Information Modelling, Environmental Product Declaration, procurement, IFC

Introduction

Advert of Building Information Modelling (BIM) [1] tools has envisioned promising prospects for a more realistic sustainability approach towards design and construction [2]. BIM is, in principle, a “modeling technology and associated set of processes to produce, communicate, and analyze building models” [3]. BIM facilitates integration of a wide variety of product and material specifications into the building model early in the design and procurement phase which, in turn, opens up plausible possibilities for various types of environmental analyses of a multitude of design alternatives in a fast and automated fashion.

Implementation of BIM tools and methodologies by different actors across the construction industry has continually gained momentum in recent decades. According to a report by McGraw Hill Construction, 71% of architects, engineers, contractors and owners in North

America have been engaged with BIM in 2012; which demonstrates a 75% increase over five years [4]. An earlier report shows that 60% of total respondents in Western Europe have been using BIM on at least 30% of their projects in 2010; while the steepest anticipated implementation curve in the ensuing years among different user groups belonged to contractors [5]. In Sweden, 46% of construction companies were using BIM towards the end of 2011 and 53% had planned to increase their levels of BIM implementation in the future [6].

Nonetheless, problems such as availability of product specific environmental data, data format mismatch and incompatibility of design and analysis tools with product specification documents and databases, now prevailing in the market, has proved to be a major obstacle. One of the initiatives for coping with interoperability problems is the Industry Foundation Classes (IFC) format. IFC is a vendor-neutral and object-based building data model (IFC-ISO/PAS 16739) for capturing building information in a standard way indifferent of the proprietary authoring tools deployed [7]. However, according to a recent survey performed on a number of IFC-compliant environmental analysis software solutions, none of them were fully capable of performing sustainability analysis [2]. The reason was that: a) none of those applications included all the indicators required for sustainability analysis; b) transfer of the building geometry from the CAD (Computer-Aided Design)/BIM tools to most of those applications had to be done manually; and c) modification of the design models with regard to the feedback from energy simulations was not fully automated (it was not possible to import the results back to the design tool). The software packages studied in the survey were Archiwizard, EcoDesigner (an extension to ArchiCAD), ECOTECT (developed by Autodesk), ELODIE (developed by CSTB), IDA ICE, ILMARI (developed by VTT), Green Building Studio (also by Autodesk), Fide and TRNSYS.

To address similar problems was the starting point for the interdisciplinary applied research project, Life-cycle-support Building product Indexing Platform (Lsc-BIP) executed at BIM Collaboration Lab at KTH.

Aim

In this paper, the first phase of the above-mentioned Lcs-BIP project is reported and demonstrated for a specific user case, procurement, through a workflow scheme. This work forms the basis for developing a federated solution performing as a building products procurement platform for environmental evaluation of design alternatives. The outcome of this study is a ground for implementing already existing tools and standards for life cycle assessment or environmental certification of buildings in early building design [8].

General Configuration

The outcome of the first phase of the Project is a set up composed of two major component systems: a web-based tool for realizing a life-cycle-support building procurement, BuildX; coupled with a BIM-enabled knowledge management platform and data sharing hub, Share-A-space.

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The former envisions web-based communication linkages with both local and international manufacturers of building products and maintains a trifold focus on competitive price, quality measures, and environmental performance. This user-friendly and informative interface eventually builds up an ever-updated interactive database of downstream product specifications using ISO formats such as Environmental Product Declaration (EPD) [9] when provided by product manufacturers. However, since EPDs still are lacking for most building products, the application offers a simplified and transparent calculation (EPD-estimator) integrated in the product database, to generate product-specific environmental data. The tool provides cradle-to-grave CO_2e emission data with the option for the manufacturer to select conservative default values if any product input data is missing.

The latter, on the other hand, receives building models from in the IFC format. This enables eliciting models from different actors who deploy diverse proprietary BIM-authoring tools for compiling design alternatives. Share-A-space (S-A-s) then implements the PLCS standard (Product Life Cycle Support - ISO 10303-239) internally to maintain a through-life-support approach to building knowledge management [10]. The PLCS format has the capacity to capture and retrieve all the changes that occur in the building information database over time; while the content of an IFC model is merely a cross-section of the ever-evolving building model at a certain point in time.

Scope and Delimitations
To illustrate the methodological solution clarified above, a proof-of-the-concept demonstration case was built up for a specific user application (architectural domain), a specific situation (procurement phase), and for a certain building material (wooden floor). Workflow scenarios were devised for the three disciplinary roles of the **Architect (A)**, the **BIM Administrator (BA)**, and the **Contractor (C)**.

Workflow Schema
Within the Lcs-BIP Project, a preliminary real-world performance of the eventual federated tool was sketched out and built up. A simplified workflow scheme of the tool lis as follows:

- **A** submits an object-based detailed design model (BIM) in a neutral format to the data management system (Figure 1).
- **BA** checks the submitted building model for possessing all required fields | if required, additional property sets are added to the model's data structure | The building element in question (floor) is queried in the model and all instances are extracted into XML (Extensible Mark-up Language) format | An XML file is exported from S-A-s (Figures 2-4).
- **C** imports the XML file to BuildX based on a certain building element/material (in this case, the wooden floor) | Based on design requirements (e.g. desired thickness, thermal transfer/U value, life cycle greenhouse gas emissions, price, etc.), a list of commercial matches is provided | The most appropriate alternative is selected | An XML file including properties of the selected product/material is exported (Figure 5).

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- **BA** registers the new XML file to S-A-s | A pre-check and comparison (between the design-intent model and the populated model) is performed before final registration of the new model | The environmentally optimized design model is submitted (Figure 6).

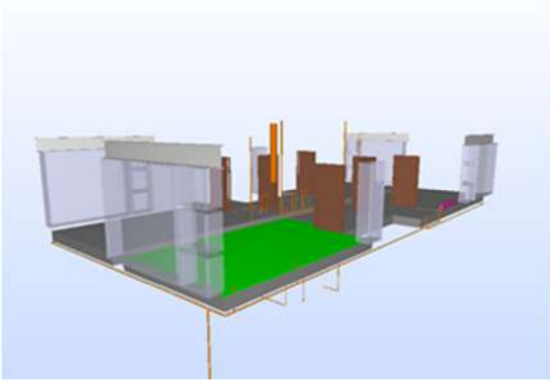

Figure 1 – A subset of the initial building model in IFC format.

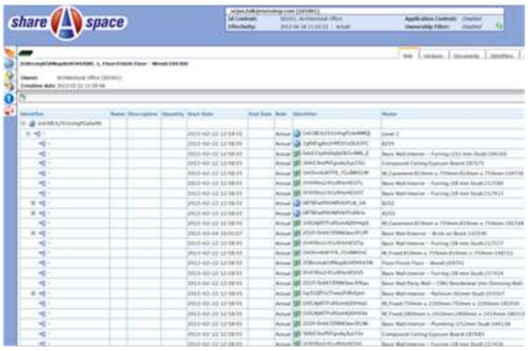

Figure 2- Building information imported to and re-structured in BIM Collaboration Hub.

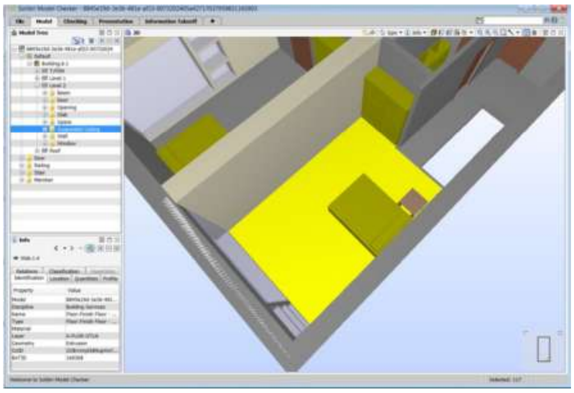

Figure 3 - The queried floor is found and displayed in the interactive view (Solibri Model Viewer).

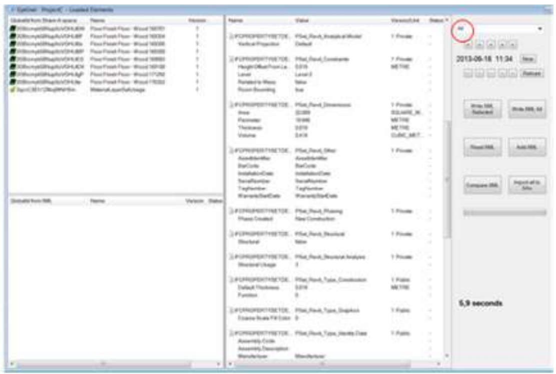

Figure 4 - Information of the floor compoenent associated with all life cycle stages are retrieved in S-A-s.

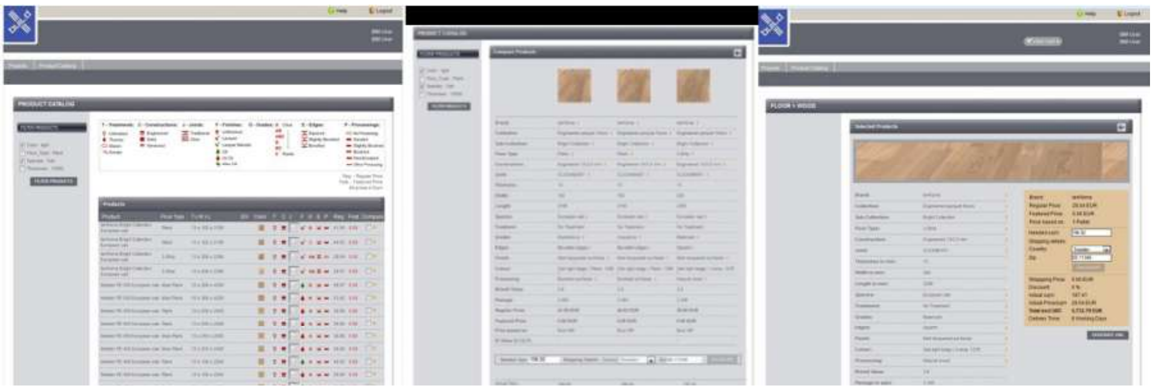

Figure5 – The floor component and its required properties exported from S-A-s in XML format are imported to BuildX; a list of matching commercial products are elicited from a market-based database and displayed; the three top items are filtered out based on the contractor's criteria; the final choice is made by the contractor and exported as an updated XML.

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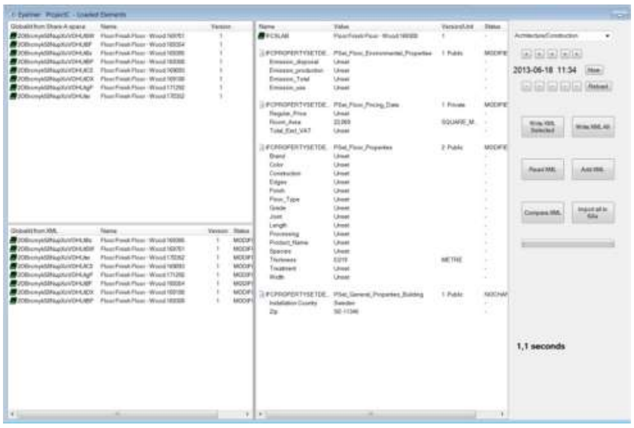

Figure 6 – The updated XML from BuildX is read and compared with the information within the Hub.

The detailed procedure for selection of the most appropriate choice of building product by the contractor will be primarily determined by the mission and objectives of the firm. Alternatively, a corporation-specific multi-criteria analysis could be applied to the items suggested by the federated tool. The eventual integration of the EPD-estimator developed within this project would enable the actors to take sustainability indicators into consideration alongside with other measures such as quality and price. Figure 7 depicts an exemplar comparative LCA report of a number of floor products created by the EPD-estimator.

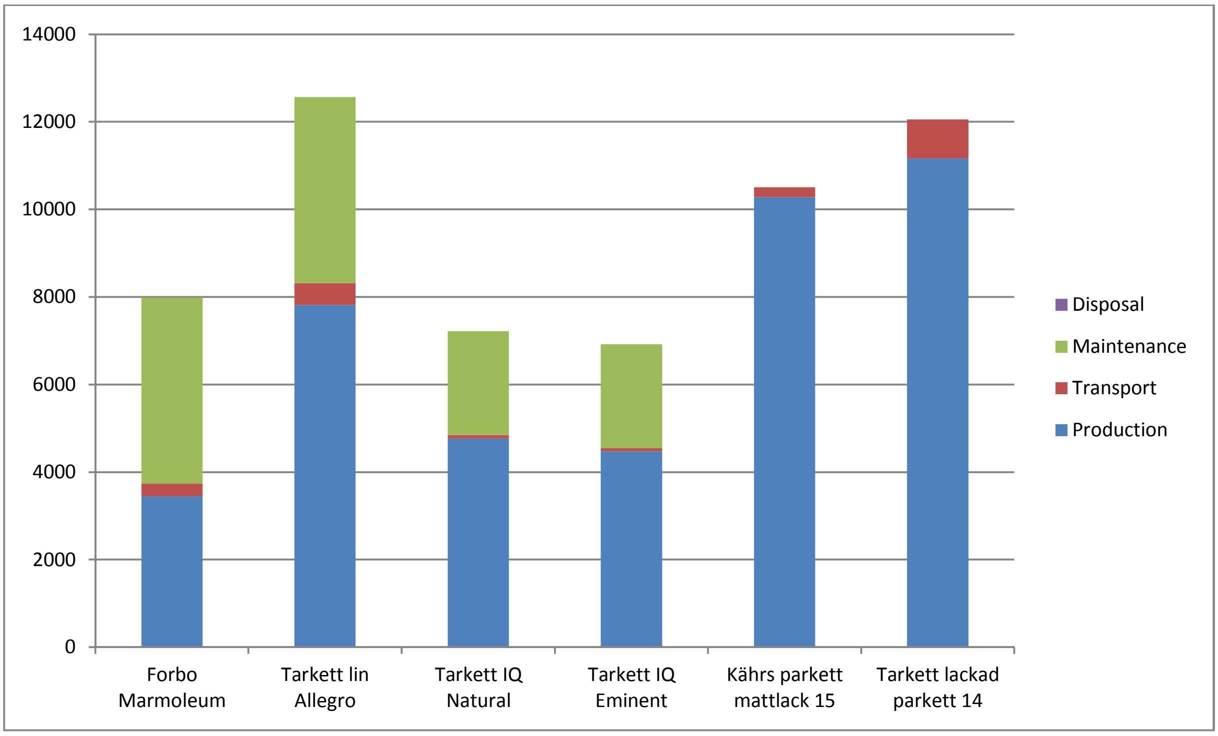

Figure 7 - An exemplar comparative LCA report of a number of floor products created by the EPD-estimator.

Discussion

In this example, the third version of the IFC model (IFCx3) was implemented. In the latest version of IFC (IFC4), however, there are two additional property sets specific to environmental analysis: “Pset_EnvironmentalImpactIndicators” which represent environmental impact indicators that are related to a given “functional unit”; and “Pset_EnvironmentalImpact-Values” that captures the environmental impact values of a specific element within a design-intent model. These two property sets directly correspond to the environmental indicators of sustainable building. Therefore, it may be plausibly claimed that the IFC model already contains the majority of the placeholders required for sustainability analysis of building products and materials e.g. energy consumption, water consumption and waste analysis [11]. Parallel initiatives by several national and international organizations are under development for eliminating the interoperability issues still prevailing. Information Delivery Manuals (IDMs), buidlingSMART’s Data Dictionaries (bsDD), Model View Definitions (MVDs) [12] and BVD4 [13] are some examples.

The long-term vision of the participants in the project is to integrate Share-A-space and BuildX and make it possible to implement that integrated platform in a loosely-coupled setting together with the design and modelling tool. The intermediate import and export acts introduced in this paper will thus be cut off through software integration. This will result in a more smooth and user-friendly procedure. Thereafter, the outcome will be developed further to also include other phases, disciplinary domains and materials. To enable environmental assessment of design alternatives, the current simplified carbon footprint tool needs to be developed further, for instance to cover more products and additional environmental impact categories.

Conclusions

BIM technologies offer promising prospects for improved sustainability approaches in design and construction. However, problems with interoperability hinder early implementation of sustainability analyses or impede reporting the results of the analyses back into design applications.

The federated solution introduced here for environmental evaluation of design alternatives is composed of a web-based tool for life-cycle-support building procurement (BuildX), coupled with a BIM-enabled platform and data sharing hub (Share-A-space). The system assists users to maintain a trifold focus on competitive price, quality, and environmental performance of the final product. The overall workflow of the system is explained through an exemplar scenario with the three disciplinary roles of an architect, a BIM administrator and a contractor. Building information is exchanged among different components of the system through a number of compatible formats, namely, IFC and XML. The eventual decision on choice of building products and materials in real-world cases will, however, be influenced by the way corporations would prioritize different measures.

The pre-assumption for this study is the downstream availability of environmental specifications of building products and materials in standard formats. Several international initiatives are in progress to realise this. The long-term vision of the participants in the project

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is to integrate Share-A-space and BuildX and make it possible to implement that integrated platform in a loosely-coupled setting together with the design and modelling tools.

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Search for the environmental indicators relevant for the building sector

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Abstract: *Life cycle assessment (LCA) is an internationally recognised methodology to calculate the environmental impact of goods and services. It is widely used to estimate the environmental impact of building products. Despite the general acceptance of the life cycle approach and the methodological steps (i.e. goal and scope definition, inventory, impact assessment, evaluation and interpretation), there is still a lot of debate on specific methodological issues. This paper focuses on one important challenge, namely the choice of environmental impact categories and corresponding indicators to be considered for the assessment of buildings and building products. More specifically, this paper discusses the balance to be found between assessment efficiency and comprehensiveness. Based on the experience in several LCA studies of buildings and building related products in the Belgian and French context, the identified relevant indicators are presented and discussed. The lessons learned are described and recommendations are formulated.*

Keywords: building sector, efficiency, environmental indicators, holistic assessment

Introduction

Life Cycle Assessment (LCA) is a widely used approach to calculate the environmental impact of buildings and building products. This is reflected in several norms (e.g. EN15804 (1) and EN15978 (2)) , guidelines (e.g. EeB Guide (3)) and simulation tools (e.g. GreenCalc (4), e-tool (5), e-LICCO (6), IES-VE (7)). Different dabases moreover exist with environmental data of building products based on the LCA method (e.g. NIBE (8), OVAM-MMG (9) and EPDs (10) in general). Unfortunately these decision-supporting instruments use amongst others different system boundaries, different life cycle inventory data, different indicators, different impact assessment models and hence are not consistent. This leads to confusion and makes it difficult to interprete and to compare the environmental impacts of buildings and building related products.

This paper focuses on the selection of environmental indicators. The aim is to contribute to the ongoing discussion on relevant indicators for the building sector. The paper reports the outcome of several research projects, both in Belgium and France and compares their outcomes regarding the relevance of the environmental indicators. The assumption is that it will be easier to interprete LCA studies of buildings and building products once we have a better insight in the relevance of the different indicators. It is furthermore assumed that a more limited set of indicators would lead to less contradictory indicators and hence could avoid the need for subjective weighting. Moreover, this insight could on the longer run contribute to a