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AN IFC BASED DESIGN CHECK APPROACH FOR THE OPTIMISATION OF MATERIAL EFFICIENCY IN THE BUILT ENVIRONMENT

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Abstract. Compared to other industries, the built environment is still the largest and one of the least efficient consumers of resources. Existing measures and procedures for resource recovery and reuse are focused on the demolition phase, when the composition of materials and structures is mostly unknown and hard to be analysed. Therefore, these measures are somewhat inefficient for overall high-rate material recovery. The enhancement of the integrated semantic planning process by the introduction of the IFC unified data standard and BIM technology is a first-time opportunity to track, analyse, document and simulate all relevant players, parameters and processes with an impact on the resource and material efficiency through the entire life cycle of a building in the design phase of a building project. The presented work explores the potential of IFC to serve as a framework for achieving a higher material efficiency in the built environment. A proposed design check approach for the simulation and optimisation of material efficiency in a building over its life cycle is based on a system of key parameters and actions organised in logic trees. The parameters and actions are translated into IFC objects. Additionally required IFC objects and properties are identified and described.

Keywords. BIM; IFC; integrative design; material efficiency design.

1. Introduction

Unlike the majority of the manufacturing industries, the construction industry is one of the very few still missing a systematic design approach to react to global environmental, economic and social trends in the context of uprising resource shortage. Recent studies confirm that the built environment is the greatest consumer of resources (50%) and energy (40%), producer of greenhouse gases (40%) and land de-aggregation (70%) (IEA 2009). Due to the systematic implementation of Design for X (DfX) approaches in the last decades, industries such as the automotive or the electronics industry have achieved nearly closed material cycles by enabling high reuse-rates and minimising material resource losses over the product life cycle as well as the demand of raw materials input (Shu and Flowers 1999, Toyota Motor Marketing Europe 2001).

This paper presents the first two steps of a research project, the aim of which is to propose a concept for the closing of material cycles in the built environment. The concept is based on the principle of the integrated design process, utilising the unified data standard IFC (Industry Foundation Classes) and current BIM (Building Information Modelling) software as a platform. Its first phase consists of the following steps: a) a direct confrontation of the building design process with best practices from high-performing industries in terms of material resource efficiency, dealing with the specifics and deficits of the construction process with regard to the implementation of an integrated design check approach and b) the development of an analytical model, consisting of concrete design parameters, measures and processes linked in logic trees as well as the translation of the key values into IFC objects.

2. Car design vs. building design

Currently, the automotive industry achieves a recovery and recycling rate of 85 weight % and 5% energy recovery from end-of-life vehicles with a target of 95 weight % and 10% energy recovery for 2015 as a result from a systematical integration of Design for X approaches in the design phase (Toyota 2001). The measures considered in these approaches are focused on the restricted use of compound materials in correlation with the choice of connections for components and elements in the product to increase recycling, recovery and reuse rates and decrease the disassembly time and sequences. Basic requirements for the practical applicability are: a) the integrated planning process in which all actors over the product life cycle are participating, b) the explicit implementation of DfX methodologies focused on material efficiency in the product design phase and c) the legislation, which is the crucial requirement for a wide implication of these approaches in practice.

As stated above, the construction industry is significantly less efficient. The reasons for this discrepancy are complex. Among others, these are: a) the uniqueness and high complexity of buildings compared to products of other manufacturing industries, which is a significant barrier for the introduction of standardised design approaches; b) the extremely long life time of buildings compared to other products, which means that designers lack the possibility of empirical feedback on the design performance over the whole life cycle; and c) the standardised building design process, which is based on strictly split design activities among the parties, often performed in different data standards and IT systems. These reasons are widely recognised as a fundamental weakness for the introduction of integrated, interdisciplinary design approaches in the construction industry (Austin et al. 1999).

3. The analytical building model

The proposed analytical building model has two main objectives: It provides the structure for a substance and material map, which documents the location of materials and their properties (physical properties like material type or density, but also analytical properties like recyclability or composition). Furthermore, it supports the identification of process and parameter intersections, where optimisation, data input or design assessment are possible or needed.

The proposed functional area division originates from three main considerations towards material management over the life cycle of a building: First, elements and products that have the same function can be linked into groups with identical or similar physical properties, which could enable material and structural aggregations and/or optimisations during the building design process. Second, elements with the same function often have similar life durations. Thus, there is a strong correlation between their respective times of disassembly as well as the possible recycling of their materials and their return into the built environment material cycles. Third, designers have to be able to make detailed changes to the physical and material efficiency related properties of elements and structures. This is highly available where design teams decide over all parameters of a building element (geometry, constraints, materials etc.) and significantly restricted where they rely on pre-manufactured products. Therefore, the building model map is divided into two main branches: “designed in project” and “pre-manufactured” (see Figure 1). Accordingly, in the map the term “building element” describes elements completely designed by the design team while the term “building product” refers to pre-manufactured building elements.

Based on these three considerations, the building is divided into five functional areas: 1) “foundations”; 2) “bearing structure”: all elements transferring forces; 3) “building envelope”: all elements dividing internal and external environment; 4) “finishings”: all elements that form and complete the internal building space structure (doors, dividing walls etc.); and 5) “services”: all electrical, heating, cooling, air-conditioning and communication services (as well as all additional special services arising from the specific building use).

These areas are assigned either to the “designed in project” or to the “pre-manufactured” branch or to both. In the following, the hierarchical structure within the branches as well as the reasoning behind it is outlined level by level.

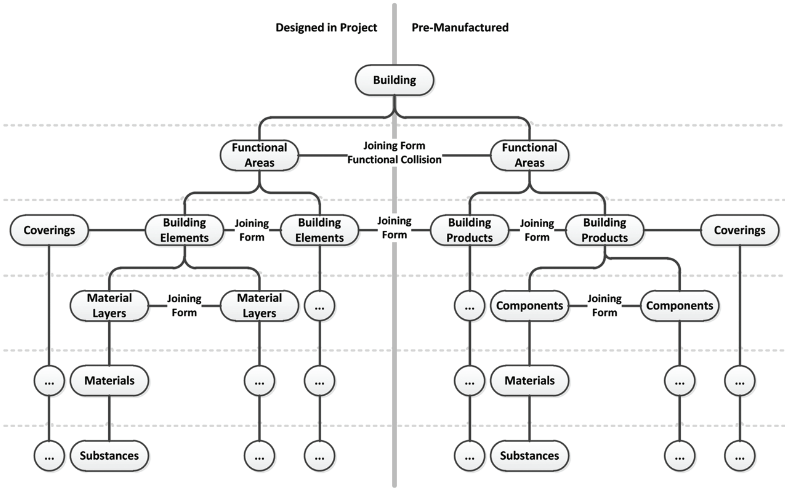

Figure 1. Proposed building model map.

3.1. THE “DESIGNED IN PROJECT” BRANCH

3.1.1. Substances

In this model, “substances” refer to material compounds on a chemical substance level that are not stand-alone materials of the building elements. There are two main arguments for the inclusion of substances in the model: human health and safety issues in the context of the comparably long life cycle of buildings and, secondly, material recyclability and reusability.

An important step towards substance management in building materials in the context of human health and safety issues was achieved with the introduction of the Material Safety Data Sheets (MSDS) with the regulation 91/155/EEC and the REACH regulation 1907/2006. Although they do not cover all substances (e.g. nano materials), they deal with substances and material compounds that could become hazardous or harmful in any phase of their life cycle. However, as material sciences belong to the most dynamic and progressive scientific areas, knowledge about materials and substances changes constantly. Thus, substances considered as harmless in greater amounts in the design phase of a building, could emerge as hazardous in small concentrations over time (e.g. asbestos, cadmium compounds).

Therefore, a suitable form for the exact localisation and complete documentation of substances in buildings beyond the requirements of the current MSDS regulation is necessary.

With regard to the returnability of materials in closed-loop material cycles in the built environment, there is a need for exact qualitative documentation of substances, too. Detailed knowledge about the exact compounds of a material is a crucial requirement for material recycling by means of well established technologies and methods as well as for the development of new, more efficient recycling technologies and approaches.

3.1.2. Materials

The term "materials" refers to the physical properties of a stand-alone material as well as additional analytical properties defined in this paper. These new properties stem from an analysis of the DfX-based material resource efficiency achievements in the automotive and electronics industries in the context of a fully integrated design process. They will be assigned to a design logic check and require a decision from the design team. Materials should be checked for recyclability in correlation with existing recycling technologies, allowing for recycling and reuse without downgrading (i.e. compound materials that can be recycled back to the same material compositions would be preferred).

3.1.3. Material layers and layer connection forms

Material layers inherit the complete material property set defined on the previous level and additionally contain the geometrical and location data parameters. The connection form between the single layers will be assigned to a design logic check, since inseparable layers result in a compound element, which, in general, can neither be reused nor recycled.

3.1.4. Building elements and joint forms

Building elements inherit the properties of their composing material layers and are assigned to groups. A check of the separability of the element joints will verify the exchangeability of the element throughout the life cycle in order to avoid conflicts with other elements resulting in material dissipation.

3.1.5. Functional areas and geometrical collisions

Building elements and element groups with the same function are assigned to a functional area. It is assumed, that the functional areas "foundations" and "bearing structure" are generally located in the "designed in project" branch while "finishings" and "services" are found primarily in the "pre-manufactured" branch and the "building envelope" is assumed to intersect with both. Several different logic design checks will be performed on this level: the first is focused on the geometrical collisions between functional areas and should verify that – if available – the constructive solution still allows for the separability and exchangeability of elements. One example for a geometrical collision of functional areas is a cooling floor ("bearing structures" and "services"), which is represented on the element level by the embedding of cooling pipes in the concrete floor slab.

The next check addresses the overall design optimisation and focuses on the element groups in their respective functional areas, testing for minimisation/optimisation of the number of distinct elements in a given functional area and – subsequently – the material variety of said elements.

3.2. THE "PRE-MANUFACTURED" BRANCH

Generally, the objects contained in this branch should fulfil the same requirements and should be assigned to the same design logic checks as the elements from the "designed in project" branch. However, the data availability and quality as well as the form of documentation in this branch can strongly vary depending on the respective product and manufacturer. Hence, significant uncertainties could occur in the model within this branch and reduce the quality of the design check.

3.2.1. Substances, components and products

Crucial in this branch is the correlated impact of regulations and data standards used, since the designer cannot influence data quality and availability. Regulations guarantee the (manufacturer-delivered) data content and quality flowing into the model, while data standards ensure the transferability and automated usability of the data. With the evolution of the IFC data standard and BIM-based building design, some building product manufacturers have already begun to deliver the complete product documentation additionally as an IFC model or in compatible formats. These IFC product models can be directly embedded in the BIM and ensure a direct and complete exchange of metadata. The workflow and data exchange in such a case is the subject of a case-based research by Babic et al. (2010). In this context, an equal grade of data availability, detail and unified data standards on both sides ("designed in project" and "pre-manufactured") is a prime concern. Large deviations between the branches (e.g. very detailed "substance" data on the "designed in project" branch and no information on the "pre-manufactured" branch) would lead to unacceptable result uncertainties. In the regional legislation in some countries (e.g. Denmark) IFC-format documentation is compulsory for publicly aided building projects, thus enabling the genesis of a resource data map for the built environment that can serve as a repository for future building resource management endeavours.

3.2.2. Functional areas

In the "worst" case of a design-bid-build organised building project, every single functional area is designed, ordered and built by a different sub-contractor and subsequently documented in a data format of his own choice. In this case, even given an active regulation demanding extended data availability and quality, the existing detailed data from the functional areas may be archived, but cannot actively be used after the completion of the building. Although the relevant data is available, it is downgraded to a waste product of the planning process by its lack of transferability and exchangeability (due to different data standards) and the sequential nature of the global design process. This gap is automatically bridged in the context of an actively implemented, IFC-based, fully integrated planning process.

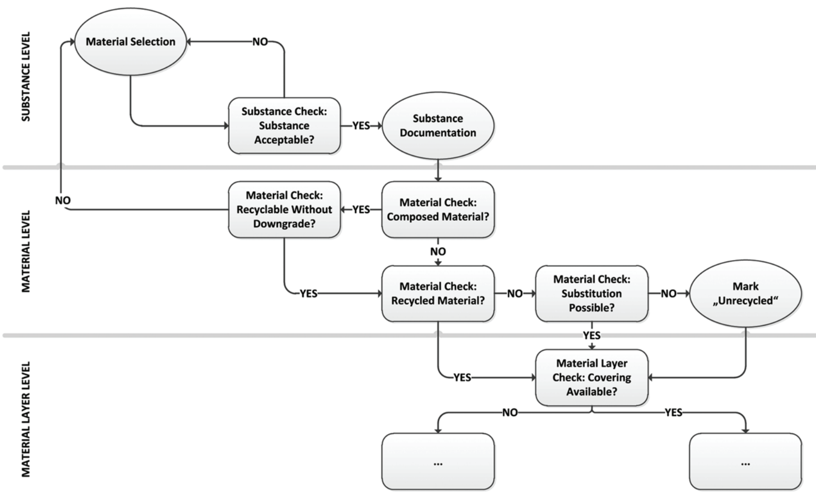

Figure 2. Excerpt of "designed in project" branch logic tree.

4. Logic-check trees

Based on the analytical building model map, logic flows for decision support can be identified. The logic trees are defined so as to offer a transparent and clear decision support for designers and give an instant feedback on the results of a decision.

The aim is to achieve a fully automated design check where designers can decide and understand the results of their decisions, but are not required to possess an extended and highly specific knowledge about processes and parameters pertaining to the material efficiency design check. In order to achieve this, a main requirement for future regulations is to verify that the substance and material data required will be delivered in adequate detail and quality and in the corresponding data format by the manufacturers.

In this paper, a section of the "designed in project" branch logic tree is presented that deals with the substance and material levels (see Figure 2).

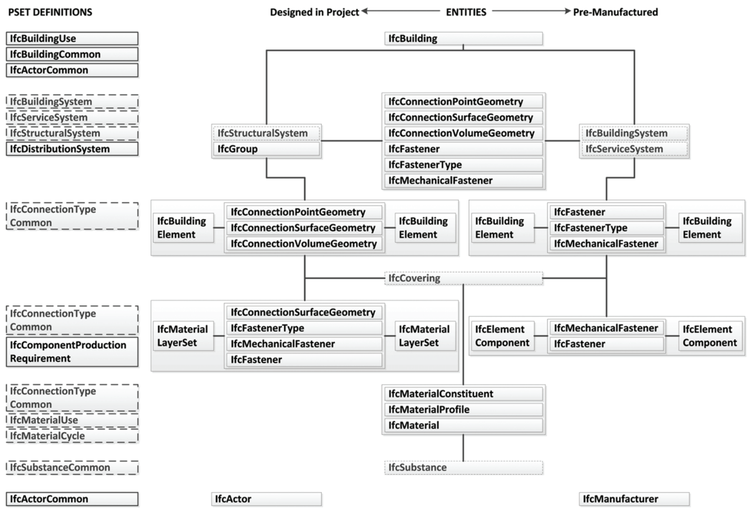

Figure 3. IFC-based data model diagram (extended or proposed are represented with dash lines).

5. The data building model

The translation of the analytical building model into IFC is based on IFC 2x4 RC3 (October 2011). The model primarily consists of IFC entities for the translation of the model elements and IFC property set definitions for the description of complex relationships which will be the subject of a design check. When required, additional IFC objects are proposed or the content of existing objects is extended (see Figure 3).

5.1. ENTITIES

Basically, IFC does not differentiate between "designed in project" and "pre-manufactured" building elements. The differentiation is therefore given by the assignment to an IfcActor for the “design in project” or IfcManufacturer for the “pre-manufactured” building elements. To stress the difference, additionally an IfcStructuralSystem is proposed. An additional IfcServiceSystem defines explicitly the “services” functional group. The existing IfcBuildingSystem is assigned to general and special functional areas that are heterogenous (i.e. can be assigned both to “designed in project” and “pre-manufactured”) such as “finishings” or to special functional areas arising from the specific building use.

Another additional IFC entity proposed is IfcSubstance. It corresponds to the “Substance” function and definition in the analytical model and is subordinate to IfcMaterial and IfcCovering in the data model.
The material usage in the building is defined on the material level by IfcMaterial as well as IfcMaterialProfile and IfcMaterialConstituentSet for the identification of composite materials.

5.2. PROPERTY SET DEFINITIONS

For the purposes of an IFC-based design check (which is the subject of a later phase of the project and not presented in this paper), new IFC property set definitions are defined. Exemplarily, the property set definitions for substances and materials are demonstrated in the tables below.

TABLE 1. PropertySet Name: Pset_SubstanceCommon.

Name	Data Type	Definition
Reference	IfcIdentifier	ReferenceID for the specific type in the project
Listed	IfcBoolean	Indicates whether the substance is marked as listed according to current safety classifications
Composition Rating	IfcBoolean	Indicates if the substance is identified as an “impurity” with regard to the containing material and will therefore cause a downgrade in the recycling process

TABLE 2. PropertySet Name: Pset_MaterialCycle.

Name	Data Type	Definition
Reference	IfcIdentifier	ReferenceID for the specific type in the project
Composite	IfcBoolean	Identifies if the material is a composed material (according to manufacturer data sheets)
Recycled	IfcBoolean	Identifies if the material is a recycled material
Recyclable	IfcBoolean	Identifies if the material is recyclable

6. Conclusions and further work

In the context of a fully integrative design process, available software interfaces and unified data standards, the information transfer and storage can be organised automatically into a building model and thus, be used, adapted and completed over the life cycle of a building. The design check logic flow based on the models presented in this paper will be applied on a case study performed completely in a BIM to identify further implication deficits. For the optimised data model and design check logic flow, an IFC rule-based checking algorithm according to the methodology of Eastman et al. (2009) will be defined and tested on building projects in practice.

As a future challenge, the management of intellectual property, patents and corporate manufacturing secrets for building products will have to be addressed. The hypothesis assumed is that the qualitative documentation of the substances in pre-defined percent ranges is the deciding factor and not the exact quantitative description – this should effectively ensure a balance between industry and owners' interests.

Nevertheless, the history of Design for X adoption in the automotive and electronics industries shows that without the corresponding regulations, the environmental and social incentives most likely will not be enough to initiate the changes necessary.

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