Life cycle modeling of buildings

Life cycle impact assessement and building specification

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The decision to take the building as built as the pivot of product modelling, means that the description of a building has to be process based (building process, operation process) and object based (construction elements). The link to existing catalogues of building specifications as a basis for process description and to existing cost and simple energy calculations is presented and discussed.

Building specifications, catalogues, database model, ecological impact, life cycle analysis

1 Introduction

One of the major areas of interest in our work is the life-cycle analysis of buildings, as built and as being planned and specially the impact on the environment during the lifecycle of the building such as production of construction products, construction, use, renewal and demolition. Each of these impacts can be computed by small and independent tools such as spreadsheets, but our goal is that the information given into one step or produced in one phase can also be accessed or used in other stages. So we need a general model which can hold all information needed during the different phases.

The model we develop is based on predefined components which are described by materials, processes and information about their structure. These components can be used as a toolbox to configure buildings according to needs. They are represented in a uniform way but in different scales such as systems, parts and details. The scope of the model extends from buildings as one unit, parts like walls and ceilings, to details like connections or cables. Use and renewal are treated as scenarios which can be applied to buildings being planned or as built. These scenarios are organized as operations and are written in scripts which can be modified.

The computed results can be used in CAD-tools of software vendors. Early design stages can be supported through aggregation of averaged elements (statistical data) which can be used as default values till the user has taken a decision what element is to be used. The whole model, the methodology of collecting data and the computable results are organised as an open system which can be changed and extended according to new requirements (for example costs and energy consumption during use).

2 Catalogue

The CRB (Schweizer Zentralstelle für Baurationalisierung) is providing a catalogue of building specifications (NPK, Normpositions-Katalog). Amongst other catalogues with data derived from this NPK this organisation is also providing a catalogue of building elements (BEK, Berechnungselemente-Katalog).

The main goal of these catalogues is to support cost-targeting. These catalogues are widely used in the suisse building industry and are the base of standardizations in the suisse market.

2.1 Building specifications

The catalogue of building specifications (NPK) holds ca. 15000 different entries. Each of these entries describes one of these 'atomic' units which are referenced during calculation and accounting. Since the goal of the catalogue is to give support for cost calculation and cost targeting, the description of these building specifications and the materials and work is in a way which is useful in respect to costs, but they give only limited support for energy- and massflow analysis.

Examples: The catalogue from CRB holds one entry which is giving the costs for delivery and mounting of a window. The costs given are related to the size of the window but there is no information about the mounting materials (mounting foam, screws,etc.).

Another entry giving the costs for concrete form per square meter of concrete wall, but there is no information about the materials used to build the form, about the machines used and about the waste produced. However this missing information is neccessary for doing energy and mass flow analysis of buildings.

2.2 Elements

Since using these atomic units is getting quite complex and difficult to handle if many of these building specifications are involved, CRB is also providing a catalogue of pre-configured building elements (BEK) with ca. 18000 entries.

Each of these entries describes a complete and more complex element (e.g. one square-meter of concrete wall, thickness 11.5 cm, including concrete form, coating etc.) by assembling these elements out of building specifications and their relative quantities per element.

The level of building elements is the appropriate level of detail in order to describe complete buildings for doing energy- and massflow analysis. Once a building is given by a list of building elements and their quantities, it's possible to generate a list of all building specifications and their quantities by using the catalogue.

2.3 Transformation

Since the building elements as given by the CRB catalogue are holding informations neccessary for cost calculation but not all the informations neccessary for energy- and massflow analysis (not enough data about materials, machines, waste etc.), the missing data have to be added. Some of these additional informations are: machines (which type of machine, duration of use), exact details about materials or additional things like nails, screws, glue, foam (exact quantities) and information about transports, the waste being generated and average life expectancy.

Some of these informations are implicitely given by the description of the building elements, some are hidden in the description of the building specifications. In any case there must be a person with sufficient knowledge of the construction process in order to extract the hidden information from the given description and to transform the description of building specifications given by the CRB into a more detailed machine-readable form.

With this more detailed machine-readable form it's possible to decompose a building given by its building elements into a complete list of materials and machines (i.e. construction products) involved which is the base for the energy- and massflow analysis. This decomposition can be stored in a DBMS.

3 Database Model

The DBMS model (or product model) is separated in four parts: building or project, building parts, construction elements, construction products and machines. The DBMS applications are: reading and storing the descriptions of buildings or projects; transforming catalogue elements to DBMS entities; transforming building specifications to related DBMS entities; aggregation and analysis; writing output files of results and exchange files, which can be used in other applications (e.g. spread-sheet).

3.1 Construction products and machines

Construction products like screws, windows, stones and machines are the basic objects of an energy and mass flow analysis. All construction products are represented according to their specific characteristics in a few database classes: e.g. windows per piece; screws as an assembly of individuals; prefabricated profiles per meter. Some of them are described geometrically, others in materials and weight per piece or number of pieces. However all of them share one type-window (a common behaviour). This type-window enables the application to treat them uniformly as a so called *thing*. Machines are represented with power load, average use per year, weight and materials. They are different from construction products, but they also share the same type-window (are represented as a thing). One aspect of the type-window is the reference to one or many inventories. This relation is the key concept of the energy and mass flow analysis capabilities of the system.

Machines and construction products are unique database entities (they are so called singletons). Other database entities only hold references to these singletons. The uniform representation of construction products and machines enables use to treat mass flow (materials) and energy flow (energy consumption of machines) in the same way on the next hierarchical level of the database model.

3.2 Construction elements

Construction elements are divided in two different database types: elements and components. Elements are equivalent to catalogue elements. Components are related to building specifications. They appear in two different ways: as generic and specific types. A generic type is a collection of specific types. Generic types do not hold any references to things, only specific types do. A specific component holds references to things without any limit (logically). It can hold references to things and can establish references between things using a relation called connection. A connection itself can hold references to so called connectors and machines (both represented as things).

A generic element holds references to generic components. It is the average representation of all specific components which are referenced by these generic components. A specific element only holds references to specific components. It is a well defined representation of one existing building part.

Generic representations enable us to analyse average mass and energy flow of a building part. Specific representations gives us the possibility to compute energy and mass flow of one given building part and to compare the results with other specific parts of a similiar kind.

Generic elements and components are prototypes in the context of the whole database population. They are singletons in the context of a given edition (revision) of the catalogue. Construction elements do not have any individual behaviour. They are comparable but there is no possibility to identify one of them as a wall, a roof or ceiling. They are collections of things and do organize these things in a given way according to a defined formalism. This part of the model is comparable to Eastmans EDM.

3.3 Building Parts and buildings

Buildings and building parts represent real or planned buildings. This part of the model is divided into more than two hundred database types, including types called systems which do represent assemblies of more or less equal building parts (e.g. outer walls, cold water piping, electrical installation). The whole structure is comparable to building models like the proposed models of Bjoerk, Waard or Combine. It serves as tool to compare buildings, systems of a building or the parts themselves. A few topolocical informations can be added (e.g. orientation, layering of building parts) to enable primitive energy calculations and the computation of the behaviour of a building during use, renewal and demolition. Building parts hold references to generic or specific construction elements. This references enable an application to compute the whole energy and mass flow of every individual part of buildings.

4 Aggregation and Analysis

Aggregation of life-cycle-costs can be done on several levels: building, building part, element, component and thing. Is is implemented as chain of responsibility where each entity cares for itself. The aggregation is first done on the level of things (e.g. 20000 screws in the whole building). In the next step each thing is asked to decompose himself according to the given aggregation (sum of a thing in a building, building part, etc.). The decomposition can be done in several ways. Only two of them are mentioned here: level of material and level of inventory. The result of the decomposition can be written to a file. It is not stored in the database. Analysis of the results can be done with statistic toolkits.

Use and renewal will be treated as scenarios which are organized as operations. These scenarios will be described in scripts which can be modified. The target of an operation can be named (e.g. all elements which are named "E1 122.103") or can be selected through a query expression (e.g. all outer walls, oriented to the north). Two kinds of operations will be possible: replacement and repair. Replacement is possible for parts of a structure (e.g. replacement of isolation) or the whole structure (e.g. replacement of a door).

5 Implementation

The whole model is described in EXPRESS with some extensions (ONTOS dictionaries). The EXPRESS files serve as input files to ExpressLab, an C++-code generator. The object oriented database ONTOS 3.0 is used as data repository. C++ is used as programming language. The transformation of building specifications and catalogue elements is done using lex and yacc and standard C. The physical database resides on a SPARCstation running SunOS 4.x. The database model is defined through 360 C++ classes. Applications define about 40 C++ classes. A configured database including all catalogue elements and all necessary building specifications is about 300 Mbyte of size.

5.1 Trademarks

EXPRESS is a part of the ISO standard 10303. ONTOS is a product and registered trademark of ONTOS Inc., Burlington Massachusetts. ExpressLab is a product of Gopas Software GmbH, München, Germany and produces source code which calls ONTOS library functions. SunOS and SPARCstation are products and registered trademarks of Sun Microsystems, Inc..

6 Summary

What we have achieved: formal description of buildings on several levels of abstraction; formal description of components according to the needs of energy and mass flow analysis; development of the database model and transformation of the descriptions to the structures of the database model.

Till March 1996 we want to fulfill the following goals: inventory analysis of the basic construction products; computing the ecological impacts of selected buildings.

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