Towards Automatic Norm Compliance In Construction Domain

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***Abstract*—This research presents the *Ok − build* expert system for automatic detection of norm compliance in the construction domain. In the first step, the plan of the building, exported by the CAD tools using the Industry Foundation Classes (IFC) standard, is converted as Jess facts. Then, the construction is checked against the active regulatory norms represented as Jess rules.**

***Index Terms*—expert system, computer integrated construction, norm compliance, CAD tools.**

I. Introduction

Many benefits are envisaged by applying current IT technologies in the construction domain [1], [2]. The computer integrated construction (CIC) lies on the intersaction between construction domain [3] and computer science technology [4], which promisses several possible benefits [5].

This research lies at the interseaction of three different domains: construction management, norms regarding constructions, and computer standards, aiming to fill the gap [3] between construction design and plan validation. Most of the Computer Aided Design products have the capability of exporting their data under different formats, including the IFC standard, for facilitating inter-operability in the building industry. A middle-ware between the low level, specific IFC standard and high level, abstract norms is proposed to identify legal breaches or safety threats in the design of a building. The expert system component is developed using Jess [6], based on the current corpus of rules that govern the construction domain.

Building Information Modeling (BIM) is the process of generating, storing, managing, exchanging and sharing building information in an inter-operable and reusable way. A BIM system is a tool that enables users to integrate and reuse building information and domain knowledge through the lifecycle of a building [7].

[8]

The remainder of this paper is structured as follows: Section II introduces the technical instrumentation exploited in our research. Modeling the corpus of rules is detailed in section III, whilst a running scenario is presented in section IV. Section V advocates the benefits of the proposed system, whilst section VI browses related work.

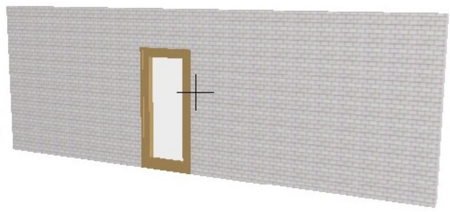

Fig. 1. A simple CAD model

II. IFC Standard

The IFC standard is developed and maintained by the *International Alliance for Interoperability*. It is a neutral data format to describe, exchange and share information typically used within the building and facility management industry sector. At the moment, all leading CAD companies support IFC by native implementations. The standard enables CAD applications to communicate with other building related systems, by facilitating the importing of the construction project by all IFC-aware frameworks.

IFC concepts are based on the notion of *objects*, *relationships*, and *properties*. An *object* is the generalization of any semantically treated thing (or item) within IFC. Its abstract super-type *IfcObject* can be instantiated by physical or conceptual items like: wall, beam, grids, virtual spaces, etc. There are seven fundamental entity types in the IFC model, which are all derived from the *IfcObject*: *IfcProduct*, *IfcControl*, *IfcActor*, *IfcProject*, *IfcProcess*, *IfcResource* and *IfcGroup*.

A *relationship* stands as a generalization for all relationships among things (or items) that are treated as objectified relationships in IFC; literally, making a relationship into a class of its own right (*IfcRelationship*). *Properties* generalize all characteristics that could be assigned to objects, reflecting specific knowledge about an object (*IfcPropertyDefinition*) [9].

In order to emphasize the IFC objects, a simple example is depicted in figure 1. This construction plan, a wall with a simple door designed with a CAD tool, represents the input of our framework. Two types are used: *IfcWall*, respectively *IfcDoor*. Translating this picture from a 3D design stage onto an IFC format, we obtain a set of definitions of our entities (see figure 2) Each line of code has a certain identifier

```
DATA;
#1   = IFCORGANIZATION ('GS','Graphisoft','Graphisoft',$,$);
#5   = IFCAPPLICATION (#1,'10.0','ArchiCAD 10.0','ArchiCAD');
#6   = IFCPERSON ('','','',$,$,$,$,$);
#8   = IFCORGANIZATION ('','','',$,$);
#12  = IFCPERSONANDORGANIZATION(#6,#8,$);
#13  = IFCOWNERHISTORY(#12,#5,$,.NOCHANGE.,$,$,$,1271317806);
...
#165 = IFCWALLSTANDARDCASE ('0V$F45CanClgRbU0PFuFlW',#13,
       'SW - 002',$,$,#162,#244,$);
#2644= IFCDOORLININGPROPERTIES
       ('2hCskD8VrExw0d4AOso$49',#13, $,$,115.,32.,
       $,$,$,$,$,$,$,$,$);
#2648= IFCDOORPANELPROPERTIES
       ('1LNxCZRB93QP$oyXAkegvZ',#13,$,$,44.,
       .SWINGING.,$,.MIDDLE.,$);
#2652= IFCDOORSTYLE
       ('3f0HGSfUXBoeQwTXmc5C9Y',#13,'D1 11',$,$,(#2644,#2648)
       ,$,$,.SINGLE_SWING_LEFT.,.NOTDEFINED.,.F.,.F.);
```

Fig. 2. Part of the IFC model.

r_1 *The window area which transmits light must be at least 1/20 of the area of the floor of that workspace.*
r_2 *The total width of all windows must be at least 1/10 of the total outside widths of all walls.*
r_3 *The standard size of a door must be a whole number, multiple of 125, between [625,2500 mm] (width range) and [1875,2500 mm] (height range).*
r_4 *Outside ramps should have a slope of max. 15% (having an oscillation of level less than 200 mm) or max. 8% (with an oscillation of level more than 200 mm).*
r_5 *The height of an outside ramp should be the most 150 mm.*

Fig. 3. Samples of construction norms.

("#" symbol, followed by a positive integer), in this way making referencing much easier; After the "=" symbol the name of a function follows, which represents the object that is going to be created. The first set of date encupsulates information about the CAD application used for generating the IFC model (IFCAPPLICATION), the person who designed the plan, the business entity or the version of the plan. The second set of knoweldge regards the spatial representation of the plan, where IFCWALLSTANDARDCASE correspondents to the *Wall* object, from the construction plan, IFCDOOR refers to *Door* object, IFCDOORLININGPROPERTIES describes door lining properties, at minimum thickness and depth, IFCDOORPANELPROPERTIES formalises door panel properties, at minimum: depth and width of the panel, whilst IFCDOORSTYLE captures the name and the description of door's style.

III. Norm Representation

This section shows some active norms from the constructions domain. The following norms [10] related to our main scenario are depicted in figure 3.

A. Norm modelling

To represent the above norms in Jess, we defined templates for the primitive object such as wall, door, window, and ramp. The templates are builded hierarchically, by exploiting the *extends* option provided by the Jess language (figure 4). Here,

```
(deftemplate quadrilater
  (slot q_width (type FLOAT))
  (slot q_height (type FLOAT)))
(deftemplate door extends quadrilater)
(deftemplate wall extends quadrilater
  (slot outside_width (type FLOAT))
  (slot outside_height (type FLOAT)))
(deftemplate window extends wall)
(deftemplate floor extends wall)
(deftemplate ramp extends quadrilater)
```

Fig. 4. Basic jess templates for representing IFC types.

```
(deffacts some-items
 (wall   (q_width 1500) (q_height 2000)
         (outside_width 1600) (outside_height 2100))
 (wall   (q_width 1500) (q_height 2000)
         (outside_width 1600) (outside_height 2100))
 (floor  (q_width 1500) (q_height 1500))
 (door   (q_width 875) (q_height 1875))
 (window (q_width 950) (q_height 950)
         (outside_width 1000) (outside_height 1000))
 (ramp   (q_width 1000) (q_height 200)))
```

Fig. 5. Modelling IFCtypes as Jess Facts.

the *wall* template extends the parent template *quadrilater*, which has only two attributes: *q_width* and *q_height*.

By parsing the IFC file, the templates are filled with the obtained measurements. The resulting Jess facts are depicted in figure 5. Several functions are developed to fill the gap between data extracted from the IFC file and the general terms appearing in the normative rules. As an example, the function *slope* in figure 6, computes the slope of a ramp, based on its width and height, whilst the function *q_area* returns the area of a quadrilater.

```
(deffunction slope (?height ?width)
  (bind ?slope (/ ?height ?width))
  (return ?slope))
(deffunction q_area (?width ?length)
  (bind ?area (* ?width ?length))
  (return ?area))
```

Fig. 6. Functions for filling the gap between IFC data and norms.

The norms are formalised as Jess rules The most important part in this section is the rule definition. The entire corpus of norms issued in the begining of the section are modelled as Jees rules in figure 7.

B. Handling inconsistencies

The *salience* property is exploited to handle contradictory norms (see figure 8. Activated rules of the highest salience will fire first, followed by rules of lower salience.

Declaring a low salience value for a rule makes it fire after all other rules of higher salience. The default salience value is zero. Salience values can be integers, global variables, or function calls. The order in which multiple rules of the same salience are fired is determined by the active conflict resolution strategy. Jess comes with two strategies: "depth" (the default) and "breadth." In the "depth" strategy, the most

```
(defrule check-door
 ?cd<-(door {q_width >= 625 && q_width <= 2000 &&
             q_height >= 1875 && q_height <= 2125})
       (door (q_width  ?w&:(= (mod ?w 125) 0))
             (q_height ?h&:(= (mod ?h 125) 0)))
 =>
       (printout t "R1 checked for door:" ?w "x" ?h)
       (retract ?cd))

(defrule check-window
   ?w <- (window {q_width > 0})
   ?f <- (floor {q_width > 0})
=>
(bind ?window_area (q_area ?w.q_width ?w.q_height))
(bind ?floor_area (q_area ?f.q_width ?f.q_height))
(if (>= ?window_area (* 0.05 ?floor_area)) then
  (printout t "R2 checked for window" ?w)
  else (printout t "R2 is breached for window" ?w)))

(defrule check-ramp
   ;;height should be <= 150 mm
   ?cr <- (ramp {q_height <= 150})
 =>
   (bind ?slope (slope ?cr.q_height ?cr.q_width))
   (if (< ?cr.q_height 200) then
         (if (<= ?slope 15) then
           (printout t "R4 checked for ramp"))
           else (printout t "R4 is breached"))
   (retract ?cr))
```

Fig. 7. Formalising norms for checking doors, windows, and ramps.

```
(defrule larger-window
 (declare (salience 100))
 (distance-to-next-building ?x)
 (test (< ?x 20)
 =>
 (minimum-window-width 1.25))
```

Fig. 8. Using salience to handle conflictual norms.

recently activated rules will fire before others of the same salience. In the ”breadth” strategy, rules fire in the order in which they are activated. In many situations, the difference does not matter, but for some problems the conflict resolution strategy is important. In the case of building verification, the priority is set by the corpus of laws particularly to a certain country and followed then by the obedience of the international ones.

An example of this kind of contradictory norm, is the *security to fire of tall buildings*, which has some parameters that need to be measured in order to determine whether a tall construction is safe or not. The contradiction appears in the case of the density of the thermal load. According to the European regulations this parameter is not enough to determine the safety of tall buildings; still, nowadays, this thermal loads it is the only measurement that decides this aspect.

C. System architecture

This section details the architecture of the developd *Ok − build* system. The framework is composed of three main parts: i) the project that is submitted for compliance, ii) the parser that selects only data that are needed to verify the consistency

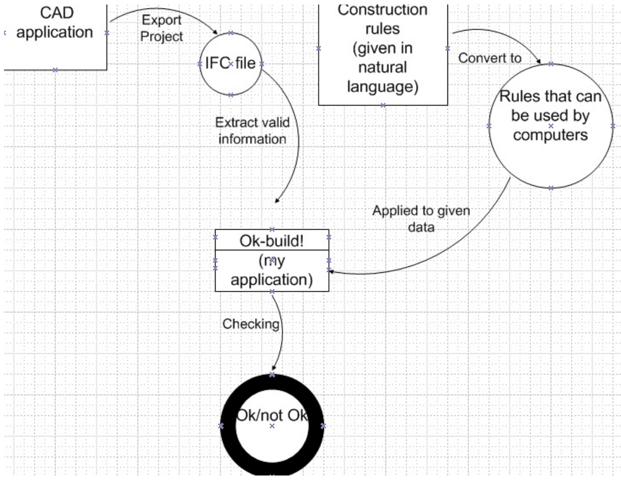

Fig. 9. Flow chart.

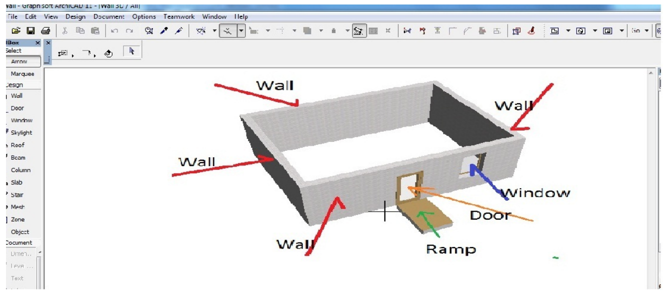

Fig. 10. A simple 3D plan created using a CAD application.

of rules, and iii) the rule-component that stores the corpus of law currently used in building domain. This dataflow is depicted in figure 9.

The CAD (Computer Aided Design) applications have the capability to convert plans from design stage into plans expressed using the IFC standard, in order to faccilitate integration with different tools. A parser was developed for the IFC file, which extracts only the required data for rule compliance. As depicted in figure 2 an .ifc file contains also a lot of redundant data, that for our application does not rise any interest. This information can be extracted from the attributes that functions that represent objects in IFC [9]. The results are saved as Jess facts, based on the pre-defined templates. The third component encapsulates the all rules that certain construction plans need to obey. When facts and rules are loaded into working memory, the *Ok − build* expert-system determines whether this plan is fully compliant or not, in which case the set of breached rules is presented.

IV. Running scenario

The proof of concept scenario illustrates a building plan consisting of a room with four walls, one door, one window, and an access ramp that can be used by persons with physical disabilities. Figure 10 depicts the plan designed into the *Graphisoft − Archicad*11 tool. The corresponding IFC file is browsed in order to extract the needed data such as: the length

```
R_1 checked for door 875 x 2000.
R_2 checked for window w1.
R_4 is breached for ramp r1.
```

Fig. 11. Definitions of functions using Jess

and the width of the door or the floor area. This facts and the active rules are loaded into the Jess engine.

The result of checking is provided using messages, as figure 11 shows. The first premise of the rule r_1 is satisfied because the door's width of $875 \in [625, 2000]$ and the heigth of $2000 \in [1875, 2125]$. Similarly, the second premise is satisfied because the both values are diveded exactly by 125.

For validating the rule r_2, the function *q_area* is called twice to compute the floor area (length=7 and width=4 and the window area (width= 1.8, heigth= 1.3). The returned values 28 sm, respectively 2.34, give a fraction of 0.083 which is larger than the minimum value of 0.05.

Assuming a ramp with the heigth of 1 meter and the width 4 meter, gives a slope of 25%. The value being greater then the maximum accepted of 15%, the system signals that the rule r_4 is breached.

V. Benefits of e-plans

The life-cycle of a building includes the following steps: design, conformance checking, maintenance, update, destruction. Having the plan formalised as Jess templates, it can be exploited in each step, as follows:

1) *Design*: By running the system as a plug-in embedded in the CAD tool, the expert system is able to continously monitor the newly elements added to the plan and it dynammically signals if a specific norm is breached. By verifying the plan during early stage, a lot of money and time are saved.
2) *Conformance Checking*: If parts of the plan are automatically checked, the time and the expertise needed to validate it would be consederably reduced. E-government and e-administration will benefit for such a framework. Moreover, the system is able to check if the current building can be integrated in the larger context of the General Urbanistic Plan of the city, by verifying global constraints such as: "There need to be X sm of green spaces at a population of Y citizens".
3) *Maintenance*: Most actors interacting with the building for small maintanance tasks do not have access to the plan of the building.
   By providing also storage for plans, this application solves partially this issue. Also, it will provide verification in case of modification proposed by the maintenance team.
4) *Update*: Any intended modification can be checked if it is applicable to the current building and under current normative requirments. Possible queries are: "Can this balcony be extended with 2m?", "Can the wall X be destroyed?", or " "Which is the maximum height that one can achieve for this building?" when an attic is wished to be added. The answers are generated by creating a new plan, containing the modification in hand, and re-submitting it for compliance checking.
5) *Destroy*: Optimised decisions are taken based on a formalised plan, where different destroying scenarios can be simulated.

An e-plan can be proved usefull in case of emergency situations. For instance, in case of a fire, the firefighters can find information related to the location of gas pipes or access points before arriving to affected area. Similarly, hospital space planning can be optimisad based on a digitilised plan of the building. Medical constraints are seen as supplimentary norms added in the same way in the knowledge base.

From the comercial viewpoint, real estate agencies can more precisely evaluate a building value by checking it against several quality standards such as thermic standard or seismic standard.

The impact of chainging the legislation can be faster and easier estimated. Assuming that a rule stipulating that "all the houses shoud have a thermal loss less that 3%" is issued. The number of homes respecting it is computed and also the costs for population needed to upgrade the buildings in order to satisfy the value can be estimated.

VI. Related Work

Several projects for supporting the development of e-plans exist. Ifc-mBomb is an IFC-based project in the UK[1], which focuses on the maintenance phase. The main objective was to develop o method to allow the information flow to pass from the building realization phase (design and construction) to the operation and maintenance phase. It enhances the functionality of a database to share information between different applications, as needed. In our research we focused on verifying the integrity of the building plan, rather than only emphasize some parts of it.

The CORENET (COnstruction and Real Estate NETwork[2]) project in Singapore exploits the IFC standard to automate the process of building plan-checking and approval [1]. One goal is to provide government-to-business infrastructure to facilitate the submission of electronic building plans. The system consists of three parts: i)*e-Submission*, today, in Singapore, almost 100% of e-plans are submitted with this system; ii) *e-PlanCheck*; and iii) *e-Info*, currently adopted by 12000 industry professionals.

The IFC Model Server project in Finland[3] stores the IFC model data in an Internet enabled database system, allowing IFC compatible applications to communicate with each other via web services. Beside the capability of storage, we have focused on integrating a verification tool, that can be used to check the plan that one just created, according to the laws currently adopted.

The ability of storing construction plans can be proved useful in the case of virtual maps or when maintenance

[1] http://cig.bre.co.uk/iai_uk/iai_projects/ifc-mbomb/
[2] http://www.corenet.gov.sg/Corenet/
[3] http://cic.vtt.fi/projects/ifcsvr/

companies need certain data in real time. Buildings such as the Sidney Opera House have been formally represented in [11]. Smart environment hierarchy [12] combines smart houses into smart building into smart cities.

VII. Conclusion

The main contribution of this study is the $Ok-build$ expert system, aiming to automatically detect norm breaching in the construction domain. Ongoing work regards i) extenting the prototype towards more realistic and complex scenarios and ii) integrating the compliace checker directly in the CAD system such that the verication to take place at the desing phase and not only when the plan is completed.

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