EXPERIENCES ON CONVERTING INTERPRETATIVE REGULATIONS INTO COMPUTABLE RULES

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ABSTRACT

The intention with this paper is to explore methods for increasing the number of regulatory statements that can be implemented into BIM-based model checking software in a valid and reliable way. The case is based on ISO 21542:2011 *Building construction -- Accessibility and usability of the built environment.* The methodology is based on classification of the structure of regulatory statements into three main categories: Transcribe, Transform and Transfer. The criteria for each category are founded on the capacity to respectively establish a direct, indirect or non-existing link between the qualitative goal/intention in the regulatory statement and the discrete quantitative metric required in computable rules. The challenge is to the increase implementation of statements classified as transformed. These types of statements are frequently used in performance based regulations. An ontology based method called "Test Indicator Objectives" is developed for bridging the gap between qualitative and quantitative expressions. Used methods identify a significant increase in number implementable rules. The results also indicate that interpretative statements, e.g. in performance based regulations, can be implemented in automatic or semi-automatic BIM-based model checking software. Used methods support large scale converting of regulations into computable rules.

Keywords: Model checking, regulations, ontology, knowledge representation, Building Information Modeling

1. INTRODUCTION

1.1 Importance of model checking for the AEC-industry

The AEC-industry is regulated by a great number of regulations, which are often updated. Use of BIM-based model checking software is increasing among professionals in the Architecture, Engineering and Construction industry (AEC-industry). Main focus has so far been mostly on clash-detection for assessment of model quality. Possibilities regarding compliance checking for verification of compliance, legality and building approval are announced as the next step for utilizing the potential of BIM. However, a limited number of regulations are implemented, and when done, it is often the simple prescriptive parts with simple logic and metric that is implemented. Qualitative performances based statements in regulations are generally omitted in implementation in BIM-based model checking software.

Public initiatives in handling of digital building applications and permissions are expected to have a critical impact on the AEC industry. Examples of solution in practical use are the CORENET e-Submission System in Singapore (CORENET 2012), Byggsøk in Norway (ByggSøk 2012), and the Planning Portal in England and Wales (Planning Portal 2012). Commercial software like Solibri Model Checker (Solibri 2012), in addition to BIM- / IFC-based model servers (BIMserver 2012), enables practical checking and review of digital models. So far has most focus been on clash detection of digital models with limited information. Increased information in the BIM content and in the rule-sets of regulations will enable support for compliance checking of selected parts of certification systems like LEED; Leadership in Energy and Environmental Design (LEED 2011) or BREEAM; Building Research Establishment Environmental Assessment Method for buildings (BREEAM 2012).

1.2 Performance versus prescriptive based model checking

The two main concepts for regulatory systems are the performance and the prescriptive based system. Both types of regulatory statements can be used within one regulation document; law, code, act, standard, public guideline, directive etc.

Performance based specifications are known as "recipe" specifications, while prescriptive specifications are known as "end result" specifications (Gibson1982). BIM-based model checking software works with discrete metric. Prescriptive statements are therefore in principle prepared for implementation into BIM-based model checking software.

Performance based specifications have quantitative goals or objectives. They are in principle much more interpretable, but might give better conditions for innovative new solutions (Oleszkiewicz 1994). Implementing this type of statements into model checking software is not a straight forward process. Organizations like IRCC, Inter-jurisdictional Regulatory Collaboration Committee, (2012) work purposefully for increased development and implementation of performance based regulations in its 19 member bodies. These countries are; Australia, Austria, Canada, China, Japan, New Zealand, Norway, Scotland, Singapore, Spain, Sweden and the USA.

1.3 Research in this domain

Model checking in the AEC industry is gaining increased interest due to use of BIM-based design software. The research domain is not clearly defined and range from technical issues and capacities in data schemas (IFC) to semantic (IFD) and logical challenges of understanding of language and presentation of rules. Other approaches projecting on the legal issues regarding performance based versus prescriptive regulations. Georgia Tech University in USA has published a number of papers, mostly with a technical approach focusing on IFC capacity. CSTB (Centre Scientifique et Technique du Bâtiment) in France is active and focus on systems for large based on database queries (SPARQL). In the Netherlands focus has been on ontology and model server and should be regarded as part of or support to this domain of research. In Belgium is Smartlab project at Ghent University working active on rule checking research. CRC Construction Innovation in Australia has developed software solutions based on JESS as rule engine, in addition to publication of scientific papers. Korea is active in BIM research and at the Kyung-Hee University research is done in compliance checking. However, the AEC related research communities are generally small without any dominating institution or research program.

1.4 Research questions and objectives

This paper is an extension and maturing of concept based papers presented at CIB W78 and ECPPM conferences by Hjelseth (2009, 2012) and Hjelseth & Nisbet (2010a, 2010b, 2011). The results in this paper are based on a case study of the complete version of the "ISO 21542:2011 *Building construction -- Accessibility and usability of te built environment*" standard. The standard has a volume of 152 pages; 42 clauses and 5 annexes.

The research questions focus on practical experiences with following two methods:

> "Tx3" as a methodology (further explained in chapter 2) for increased control of development computable rules from regulations. Starting with a classification of regulations into three types of rules; Transcribe, Transform and Transfer, gives a numeric overview of how much of the regulation can be implemented as computable rules. The methodology follows a pre-defined procedure where each step is transparent and identifiable. The objectives will be increased control of time/cost and methodology (including supporting systems) in an early phase of development of rules. The case

study will have main focus on identifying the "Transform" type of regulatory statements. These regulations are candidates for the TIO-methodology.

"TIO", Test Indicator Objectives, as a methodology (further explained in chapter 3) for increasing his paper focus on converting performance based regulations by use of a mapping methodology named TIO. TIO provides a transparent mapping between the qualitative goal/intention in regulations and the corresponding quantitative, discrete, metric in the computable rule. The TIO-methodology will be used to try to increase the number of rules that can be interpreted in BIM-based software.

2. USE OF THE T_X3-METHODOLOGY FOR CLASSIFIATION OF REGULATORY STATEMENTS

The Tx3-methodology includes three procedures; Transcribe, Transform and Transfer (Hjelseth, 2012). Please note that statements classified as "Transcribe" in previous papers has been named "Translate".

The Tx3-methodology is structured into specified levels (tiers) illustrated in figure 1. This paper focuses on transforming regulatory statements by support of the TIO-methodology, explained in chapter 3. This methodology is applied in the "#2-A, Association rule" process, marked with the doted circle in figure 1.

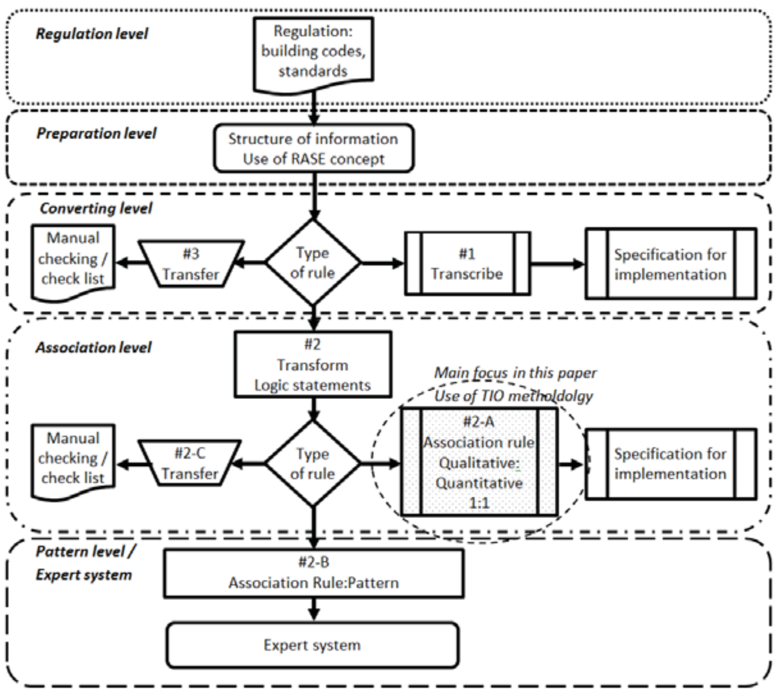

Figure 1: Flow chart of the Tx3-methodology for converting of regulations into computable rules.

Regulation level:

"Regulation" is used as a common term in this paper for all types of laws, building codes, acts, directives and standards. This paper does not focus on the hierarchy of legislation.

Preparation level

Regulations are written in a legal / technical language and must often be re-structured before they can be used as specifications for implementation in software. Preparation from free text to normative structure in tables can e.g. be done by use of the RASE-methodology. This is a semantic based mark-up methodology using the following four RASE operators: 'Requirement' 'Applies, 'Select', and 'Exception'. Practical use of this methodology is explained in paper by Hjelseth and Nisbet (2011), accessible from CIB-W78 2011 conference site. Applied on a normative regulatory text, the user highlights any clause or phrase that means: • 'shall'/'must' as a 'Requirement', • less scope as an 'Applies', • more scope as a 'Select', • 'unless' as an 'Exception'.

Converting level

The converting level classifies regulatory statements based on a simple taxonomy for identifying the target criteria of validation. This concept is named "Tx3-methodology" and is based on classification into three main categories: Transcribe, Transform and Transfer. The criteria for each category are founded on the capacity to respectively establish a direct, indirect or non-existing link between indicator qualitative or quantitative intention in the regulatory statement and a discrete quantitative metric applicable in rules. The taxonomy of type of rules is illustrated in figure 2.

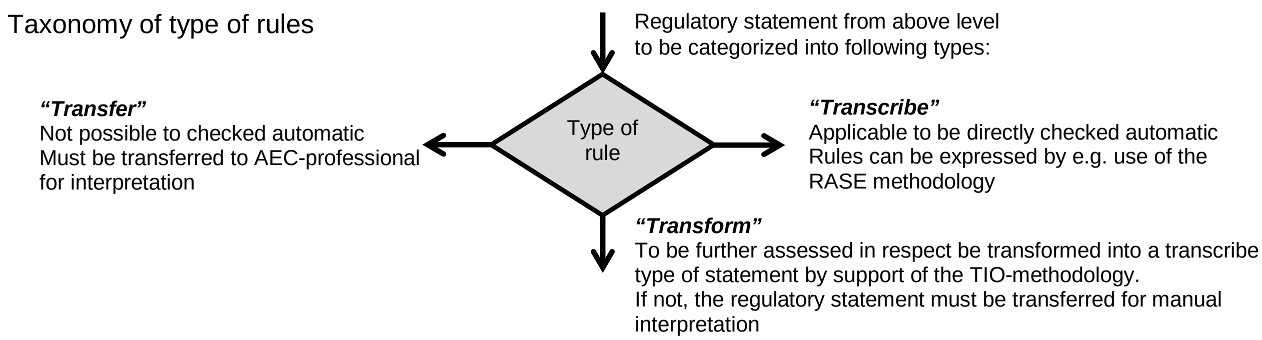

Figure 2: Taxonomy of type of rules

Regulatory statements classified as "Transcribe" can be expressed as computable rule by pre-defined procedures like e.g. RASE. The challenging part is statements classified as "Transform". Whether these statements can be expressed as (transformed to) to computable rule is decided on the "Association level". "Transfer" to skilled AEC-professionals for interpretation will often be the best solution for regulatory statements that are very dependent on its context, large number of constraints and information in the model.

Association level

The association level is in this study supported by the TIO-methodology, "Test Indicator Objectives", which is further explained in next chapter. TIO can be regarded as an "association rule" which in a transparent, valid (includes context dependency) and reliable way establishes a mapping between the qualitative goal/intention in the regulatory statement and the discrete quantitative metric required in computable rules.

Pattern level / expert system

Pattern level / expert system is an option to solve more complicated regulatory statements by support of methods and technology based on KBE (Knowledge Based Engineering), AI (artificial intelligence) and expert systems is necessary. However, the most common solution is to let a skilled AEC-professional interpret these regulatory statements manually.

3. TIO – TEST INDICATOR OBJECTIVES

3.1 Consensus about criteria for verifications

The main principle challenge is to obtain consensus between qualitative statement in regulations and quantitative metric applicable in rules. This transformation into practical criteria in BIM-based model checking software must be done without “messing up” area of application in the regulatory source. Qualitative and quantitative expressions are in principle incomparable. However, from an AEC-professional perspective, there is often consensus about practical solutions / consequences, even if they are formulated as qualitative statements. Terms (language) within AEC-industry are limited domain, and according to Sowa (2000) should a shared understanding be achievable. Ontology can be regarded as a concept for shared understanding, which focus on “what it is”, and not only “what it is called”. According to Gruber (1995) is ontology defined as formal specification of a shared conceptualization. Use of engineering ontology has been presented by Beetz et al. (2008) as a way of transforming understanding. A shared understanding should therefore be possible to achieve regarding transforming of regulations into computable rules.

3.2 Association between qualitative objects and quantitative metric

The challenge is to develop a valid and reliable way to interpret regulatory statements that enables an implementation into model checking software in a transparent, valid and reliable way. Transformable rules are characterized by an indirect relation between the qualitative objectives (goals/intentions) in the regulation and discrete quantitative metric in the rules applicable for implementation into BIM-based model checking software (Hjelseth, 2012). Examples of practical use are presented in table 1. “Test Indicator Objectives” (TIO) is a methodology that provides a transparent mapping between the qualitative goal in regulations and the corresponding quantitative, discrete, metric in the computable rule. The TIO-methodology is illustrated in figure 3 and can be done by “Top-down” and /or “Bottom-up” approach. The end result will be expressed as a single metric with a discrete value. Use of alternative values in the rule-sets can enable parametric model checking. The TIO-methodology is more detailed described in a previous paper by Hjelseth (2012). TIO is an attempt to use a simple methodology as possible for increasing number of computable rules.

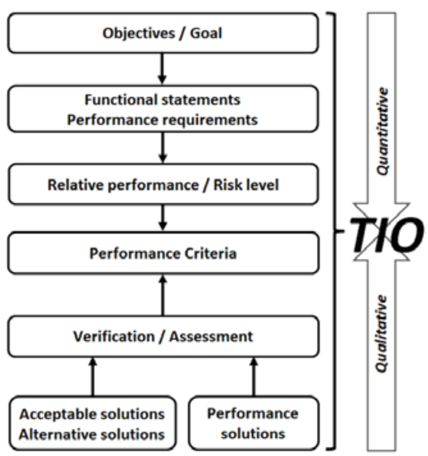

Figure 3: Relation between qualitative and quantitative regulations – scope of TIO (Hjelseth, 2012).

3.3 Example of TIO’s based on ISO 21542:2011 standard

Exploring the ISO 21542:2011 standard resulted in 90 “shall rules”, (23% of shall rules) and 89 “should rules” (30% of should rules) classified as “Transform” type of rules, representing 26% of total type of rules. For enabling automatic model checking must these types of rules with qualitative objectives be transferred into discrete metric. This will have a significant impact on the efficiency. It is important to be aware of that when the logical rule is established; these requirements can be regarded as parametric instances. This approach can enable performance checking at different levels; one rule-set with the minimum requirements, and another with higher requirements. Table 1 present a tio-dictionary where qualitative goals are transformed into qualitative metrics.

Table 1: TIO-dictionary for transformed qualitative goals into qualitative metric

Clause	Shall/ Should	Qualitative expression of goal *text of statement in ISO standard*	Test Indicator Objectives (TIO)	Quantitative metric =, <, >
Minimum dimension				
7.6	Shall	..powered wheelchair.. *If larger powered wheelchairs and scooters for outdoor use are to be considered, the outer radius of a turning space should be larger.*	Dimension of powered wheel-char, different types, in mm	*x* mm
26.3	Should	..visually contrast… *Fixtures and fittings in sanitary facilities should visually contrast with the items and surface on which they are positioned*	Use of LRV	*x* LVR
40.8	Should	..well illuminated… *Signs should be well illuminated with no glare*	Minimum illumination in lux	*x* lux
Maximum dimension				
6.8.3	Should	..as close as possible... *Location of accessible parking spaces (indoor parking) should be as close as possible to the entrances/lifts.*	Maximum distance in mm	*x* mm
18.1.9	Shall	sufficient time… *A powered swing door shall be fitted with a return delay mechanism that allows sufficient time for safe passage and for detecting the presence of a person lying on the floor within the door closing area.*	Maximum time in seconds	*x* sec.
Pre-accept solution				
18.3.2	Should	..easy to use; open and close.. *Windows should be easy to open and close. It should be possible to open and close the windows with only one hand.*	Pre-accepted (approved) type of window	Approved by *x* organization
26.5	Shall	..easy to open and close.. *The door shall have an unobstructed width of at least 800 mm, with minimum 850 mm as a recommended value, and it shall be easy to open and close. The door should open outwards.*	Pre-accepted (approved) type of window	Approved by *x* organization
Product property – Surface				
6.7	Shall	Kerbs...slip-resistance.. *Kerbs shall have a slip-resistance surface.*	Specify friction coefficient on kerbs	0.*x*
25.	Shall	Walking surfaces…slip-resistant.. *Walking surfaces shall be slip resistant.*	Specify friction coefficient for walking on terraces, verandas and balconies	0.*x*
26.3	Shall	Floor surface…shall be slip resistant.. *The floor surface shall be slip resistant, anti-glare and firm.*	Specify friction coefficient for floors	0.*x*
31	Shall	Floor coverings…slip-resistant in both dry and wet conditions.. *Floor coverings shall be firm and slip-resistant in both dry and wet conditions.*	Specify friction coefficient for floor coverings	0.*x*

4. RESULTS FROM THE FEASABILITY STUDY OF ISO 21542:2011 STANDARD

4.1 Classification of statements in ISO 21542:2011 standard into Tx3 types of rules

Table 2 is representing an overview of how the 680 statement are categorized into the three types of rules: transcribe, transform or transfer. *) Clause references include sub and sub-sub clauses. For documentation and identification have all rules a direct reference to the origin statement in the ISO 21542:2011 standard document.

Table 2: Tx3 classification of type of rules in the ISO 21542:2011 standard.

Clause in ISO 21542:2011 *)	**Shall rules**				**Should rules**				**Total number of rules**			
(Clause 1 to 4 are general parts)	**T1**	**T2**	**T3**	**∑T**	**t1**	**t2**	**t3**	**∑t**	**T1 +t1**	**T2 +t2**	**T3 +t3**	**∑T +t**
5.Approach to the building	2	1	0	3	0	0	0	0	2	1	0	3
6.Designated accessible parking space	14	5	3	22	5	3	0	8	19	8	3	30
7.Paths to the building	34	5	3	42	3	1	6	10	37	6	9	52
8.Ramps	11	2	0	13	3	1	0	4	14	3	0	17
9.Guarding along paths and ramps	3	0	1	4	0	0	0	0	3	0	1	4
10.Building entrances and final fire exits	11	2	2	15	1	3	3	7	12	5	5	22
11.Horizontal circulation	15	3	1	19	2	0	1	3	17	3	2	22
12.Vertical circulation	1	0	0	1	0	1	2	3	1	1	2	4
13.Stairs	14	2	0	16	6	3	0	9	20	5	0	25
14.Handrails	9	0	2	11	1	0	0	1	10	0	2	12
15.Lifts (Elevators)	--	--	--	--	--	--	--	--	--	--	--	--
16.Vertical and inclined lifting platforms	1	0	3	4	0	0	0	0	1	0	3	4
17.Escalators and moving walks	2	1	1	4	0	1	2	3	2	2	3	7
18.Doors and windows	18	4	4	26	7	4	7	18	25	8	11	44
19.Reception areas, counters, desks…	8	1	2	11	0	3	2	5	8	4	4	16
20.Cloackroom	1	0	0	1	2	0	0	2	3	0	0	3
21.Auditoriums, concert / sports seating	4	0	1	5	9	4	2	15	13	4	3	20
22.Conference rooms and meeting rooms	1	0	0	1	0	0	1	1	1	0	1	2
23.Viewing spaces in assembly areas	1	2	3	6	0	2	0	2	1	4	3	8
24.Bars, pubs, restaurants, etc	0	0	4	4	0	0	1	1	0	0	5	5
25.Terraces, verandas and balconies	0	1	1	2	0	0	1	1	0	1	2	3
26.Toilet rooms and sanitary rooms	54	39	3	96	30	12	4	46	84	51	7	142
27.Access. bedrooms in non-dom. build..	6	1	1	8	2	0	0	2	8	1	1	10
28.Kitchen areas	0	1	1	2	0	2	1	3	0	3	2	5
29.Storage areas	1	1	0	2	0	0	0	0	1	1	0	2
30.Facilities for guide-/ assistance dogs	0	0	0	0	2	1	2	5	2	1	2	5
31.Floor and wall surfaces	0	1	0	1	0	2	1	3	0	3	1	4
32.Acoustic environment	1	0	0	1	1	0	2	3	2	0	2	4
33.Lighting	6	5	0	11	1	10	3	14	7	15	3	25
34.Fire emerg. warning syst., signals/info	0	1	1	2	0	5	2	7	0	6	3	9
35.Visual contrast	5	2	0	7	2	0	0	2	7	2	0	9
36.Equipment, controls and switches	14	4	2	20	32	15	5	52	46	19	7	72
37.Furnishing	2	0	0	2	8	0	2	10	10	0	2	12
38.Fire safety, protect. and evacuation…	0	1	2	3	0	1	7	8	0	2	9	11
39.Orientation and information	0	0	2	2	0	3	5	8	0	3	7	10
40.Signage	14	2	0	16	9	11	12	32	23	13	12	48
41.Graphical symbols	3	3	0	6	1	0	1	2	4	3	1	8
42.Management and maintenance issues	0	0	0	0	0	0	1	1	0	0	1	1
Number of rules	256	90	43	**389**	127	88	76	**291**	383	178	119	**680**
Percent of Shall/Should rules	**66%**	**23%**	**11%**	**100%**	**44%**	**30%**	**26%**	**100%**				
Percent of rules total	38%	13%	6%		19%	13%	11%		**57%**	**26%**	**17%**	
Accumulated percent of rules	38%	13%	6%	**57%**	19%	13%	11%	**43**	57%	26%	17%	**100%**

The Tx3-methodology and criteria for categorization are explained in chapter 3. The study is based on all normative clauses in ISO 21542:2011 standard except Clause 15 "Lifts (Elevators)". In this study was this clause is regarded as requirement to a specified type of object defined as lifts (elevator) which have to be "approved" in compliance with ISO 21542:2011 and related standards. Excluding this clause is therefore considered have no consequences on the validity of this study.

This case study indicates that the applicability of regulatory statements for implementation into BIM-based model checking systems can be identified by the Tx3-methodology for classification. This can be used as a foundation for predictable development process of specifications of computable rules implementable in BIM-based software.

The normative statements in complete ISO 21542:2011 standard was classified into 680 rules (389 shall and 291 should). 57% percent of rules were classified to be "transcribe" type, which is direct into applicable rules for automatic BIM-based model checking software (The "production" of rules could e.g. be done by the semantic based RASE-methodology for structuring of statements into computable rules). Of the remaining 43% of rules - 26% was classified as transformed and applicable for the TIO-methodology, while 17% of the rules had a structure which was not applicable for transforming by TIO. Support of more advanced / context related techniques / expert systems and more advanced techniques can be an alternative to manual interpretations (Hjelseth 2012).

4.2 Distribution of Tx3 type of rules

Figure 4 illustrates the percentage distribution of rules classified by the Tx3-metholdology (see chapter 3 for information about the methodology). The rules are presented as "Shall" and "Should" level of regulation, in addition to an accumulated diagram. Please note that the area of the diagram is adjusted to number of rules.

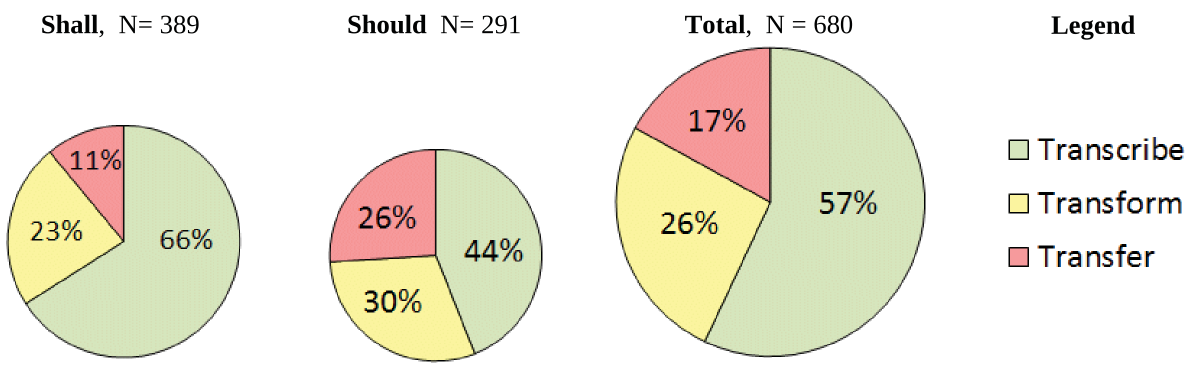

Figure 4: Overview of type of rules in the ISO 21543:2011 standard

4.3 Use of TIO-method to increase degree of automatic model checking of ISO 21542:2011 rules

Figure 5 illustrates the effect of the "Test Indicator Objectives" (TIO) as a methodology for transforming (mapping) qualitative goals in the regulations into discrete metric for enabling automatic model checking.

The results of this case study confirmed that it was possible to transform the identified 26% or "transform" type of rules by use of the TIO-methodology. The TIO transformation can be presented as a mapping table, see table 1. The impact for verification of accessibility is that the amount of rules which have to be checked manually is reduced from 43 % to 17% of total number of rules.

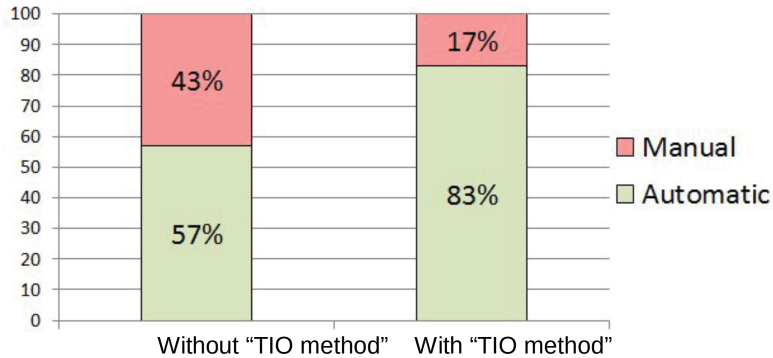

Figure 5: Effects by the TIO-methodology on model checking

5. DISCUSSION

The results are based on use of the Tx3-methodology for classification and the TIO-methodology for transforming statements applied one single regulation, the ISO 21542:2011 standard. The validity of using these methods is supported by previous papers by Hjelseth (2009, 2012) and Hjelseth & Nisbet (2010a, 2010b, 2011). Both Tx3 classification of statements and development of TIO metrics is a manual process and the precision of classification into the three types can therefore be debatable. The Tx3 classification of "transcribe" type of rules (57%) will due to direct relation be fairly unambiguous. Classification into "transform" (26 %) and "transfer" (17 %) type of rules is related to choose of method for transforming or interpreting qualitative goals into quantitative metrics. This study is founded on use of the TIO-methodology. It can be expected that some statement classified as "transform" become too difficult to obtain consensus about transformed metric and TIO must be transferred to manually interpretation. On the other hand can regulatory statements classified as "transfer" be able to be transformed in a way that is applicable for automatic model checking by support or more advanced methods than TIO, or by including constraints, context awareness and limitation in complexity for when it can be used.

6. CONCLUSION

The ISO 21542:2011 standard for accessibility was used as a case to explore the applicability of two methods:

- Tx3-methodology for classification of types of rules and how they can be implemented
- TIO-methodology, Test Indicator Objectives; for transforming qualitative goals in the regulations into quantitative metric in the computable rule

This case study indicates that the suitability of regulatory statements for implementation into BIM-based model checking systems can be identified by the Tx3-methodology for classification. The impact of this a predictable development processes that identify which statements that can be verified automatic in BIM-based software, and which regulatory statement that still must be interpreted manually.

Experiences with the TIO-methodology were that it enables a transparent, valid and reliable way to increase the number of regulatory statements that can be implemented into BIM-based model checking software. This effect is especially relevant for performance based regulations. The study indicated an increase in from 57% to 83% in amount of rules which can be verified automatic. Viewed in reduction of manually interpretations is this representing about a halving, from 43 % to 17% of total number of rules that must be verified manually.

The general experiences from this study support a shift of approach from an open development process towards use of predictable production procedures in specification of computable rules. The results can also be regarded as an indication that performance based regulation can be used as reliable bases for automatic / semi-automatic BIM-based model checking.

7. FURTHER RESEARCH

Further research will focus on whether required information specified in the rules is in compliance with the entities and property sets (Psets) in the IFC 2x3 and 2x4 data schema. The research methodology will be based on development of IDMs and BIM-guidelines. The author appreciates feed-back from corresponding projects.

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