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Ontology Models of Window Performance Characteristics for Harmonized Conformity Assessment Process

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Abstract
Conformity assessment of construction products and standardization of this process can be seen as an interface between technical and non-technical (e.g. economic, organizational, or social) considerations. It is clearly important for an efficient trade within the construction industry. However the formation and utilization procedure of standard conformity assessment needs to shift from traditional way of product performance testing to more effective and resource efficient solutions by use of advanced technology. This research investigates role of information technologies in application of conformity assessment for construction industry. The main aim is to analyze how conformity assessment can be fulfilled by development of generic product models and models for assessment processes that can support engineering solutions considering different functional and behavioural description of the modelled reality. This paper gives a case for the application of this approach as a support for window industry.

Keywords
Conformity assessment, Building product models, Ontology models, CE mark, Window

1. Introduction

For small companies in the construction industry, opening to international market is putting increasing emphasis on having standard conformity issued products. Hence the definition, CE (Conformité Européenne) mark is a mean of their economic well being and creating access to the whole European market. EU recognizes this issue by putting one of its main goals as increasing the tradability of building products and competitiveness of SMEs (small and medium enterprises) in the EU.

Mass production paradigm has lost its value through 1970s shifting its way to emphasis on individual needs and individual consumerism. This emerging approach was further detailed and defined as "mass customization" (Davis, 1987). Benros (2009) argues building industry could not adopt itself to this new paradigm and modify its production habits to mass customization as fast as other industries (e.g. automotive industry, personal computer industry). However, the requirements of harmonized CE mark procedures and consequent extensive testing, potentially jeopardizes the market of highly customized

products and SME competitiveness in the market.
Recently, the window industry in the EU is chasing for means of effective and resource efficient conformity assessment by help of information technologies, especially for custom built, small series products. Many of the existing efforts are concentrating on application of an extended shared-ITT (initial type testing) concept. Yet, there is no study known to authors of this paper on development of theoretical models for conformity assessment of windows with a generic structure; independent of component brand and open to assess innovative product performance.

This study analyses the possible effects of the application of harmonized product standard on the future of the window industry and provides a framework for a conformity assessment tool as a support for manufacturers. Ensuring product diversity in the window market while satisfying the requirements for attestation of conformity, two concerns are important: providing engineering solutions for performance assessment to decrease the amount of physical testing and developing means to ensure possibility of preserve and reuse this knowledge. Particular interest is given to the nature of manufacturing processes which requires a generic ontology model to represent all design information, composed of structural, functional and behavioural characteristics of modelled domain.

2. Scope and Motivation; CE Marking in EU

One of the two core objectives of the European Community is the development of a common market involving the free circulation of goods, capital, people and services. However, different national standards, guidelines and legislations are currently interfering with this objective. According to new approach, the harmonised standards at European level for construction products aim to provide the legislative unification for attestation of conformity in a single internal market and to afford access to that market for as many manufactures as possible. Once the harmonised standard has been published, the national standards have to be withdrawn and compliance with the harmonised standard becomes mandatory. Products to be sold in the EU that come under European Directives must carry the specified CE mark as a legal requirement enabling a product to be legally placed on the market in any Member State.

The European Committee for Standardization (CEN) provides a platform for the development of European Standards and other technical specifications for various products. Conformity assessment introduced by test and classification standards means checking whether products, services, materials, processes, systems and personnel measure up to the requirements of standards, regulations or other specifications. In building and construction industry, significant amount of the assessment procedure is based on physical testing, symbolizing the construction products have been evaluated for characteristics which influence the satisfaction for the essential requirements using the relevant evaluation method identified in the technical specifications. The specific meaning of CE marking for construction products is determined clearly: ‘For the purposes of this Directive, 'construction product' means any product which is produced for incorporation in a permanent manner in construction works, including both buildings and civil engineering works’ (Council Directive 89/106/EEC, Article 1).

The New Approach Directives provides a range of compliance routes for the products and, usually in a modular format, provide the available routes to compliance. One of the most important aspects of the new approach is its ‘prescriptive nature’, where the process is specified, but not the ultimate performance. The prescriptive standards (Allen and Sriram, 2000) provide the methodology to perform tests and processes in a consistent and repeatable way. This property of new approach directives, in turn gives flexibility in product design and exchange of innovation across borders.

3. Problem Definition; Effects of Harmonisation

CE marking specifies a minimum amount of testing for a minimum amount of characteristics that are legally required. However, extensive physical testing will be necessary after implementation of the CE-marking system for all existing and new products under construction products directive (CPD). Although for all manufacturers the transition means a change in the link between manufacturing and marketing, the focus of this paper is SMEs who mainly produce customised and small series products which face a challenge with the harmonised CE marking system. With this regard, CEC (2008) particularly emphasises the need for appropriate treatment specifically for non-series products to not to place excessive burden on the business activity of SMEs.

Small series products are mostly customised to meet specific needs. Hart (1996) defines customization as use of flexible process and organizational structures to produce varied and often individually customized products and services at the price of standardized mass produced alternatives. Among the products for construction industry, manufacturers already provide a significant level of product customization for windows, doors, cabinets, and other products with significant variability. The challenge lies on the fact that, this is reflected as a cost, in terms of time between manufacturing and marketing, and workmanship expenses. Some products, particularly those with dimensional and componential characteristics like windows, have a seemingly unlimited number of possible configurations.

This research concentrates on window designs which, due to their intended use, manufacturing properties and design characteristics, represent the challenges of customised products. Moreover, windows have specific national cultural and climatic requirements leading to many different product designs in different markets. The climatic conditions in Nordic countries have led to specific window configurations allowing triple glazing; countries have also different material preferences depending on weather, domestic industry, resources of raw material and architectural heritage. Windows unlike many other construction products are not normally made as a set of standardized sizes but are individual to the building design where their specifications are tailored according to each project. For the replacement market, windows are always made and measured to order.

As windows are building products that can be freely tradable in the common European market, the CPD indicates that such building products shall be CE marked. Performance declaration shall contain the relevant product properties by giving a specific value for a performance or by giving a performance class. The assessment of the product properties depends on the specification in the harmonized standard. Product performance can be based on testing or calculation or a combination of the two. For windows, the harmonized standard is EN 14351-1 Windows and doors – Product standard, performance characteristics – Part 1; Windows and external pedestrian door sets without resistance to fire and/or smoke leakage. This standard refers to 35 test and calculation standards for the determination of the product performance of which thermal transmittance (TT), sound insulation (SI), air permeability (AP), water tightness (WT), resistance to wind load (RWL) and Load bearing capacity of Safety devices are subject to research in this paper.

Harmonization is recognized as a factor that will affect the manufacturers to adapt their product range to respond to future market structure. In practice, the introduction of CE-marking for windows means that every window type, even single items or small series has to be tested physically and controlled under Attestation of Conformity (AoC) system 3 to determine the performance of a number of characteristics according to the product standard EN 14351-1. This entails initial testing of products by a Notified (testing) Body, a nationally approved test laboratory "notified" to the European Commission. Ticona and Frota (2008) describe harmonization to international standards is a double edged sward: in one hand, it reduces product variety, but on the other, it ensures technical compatibility across countries. The introduction of CE-marking for windows will raise two main interests on local window-manufacturer with possibly contradicting effects:

i. Technical and Economical Concerns

- *Product diversity as a competitive strength:* Manufacturers need to incorporate different product styles in their ranges in order to cover different product requirements either for local need or different climates in potentially open international markets. Moreover, harmonization will create a more competitive market even if manufacturers choose to remain with their local customers. Katz and Safranski, (2003) discusses the SMEs will need to respond rapidly, both at home, and also in international markets, to capture and keep customers in foreign markets.

- *Extensive physical testing*: The costs for testing increase since most of the window types (approximately 80% of all windows) are produced in small series which requires declaring the performance of a single window. This in return affects market sustainability and product diversity if manufacturers adopt a strategy to limit their product portfolio to avoid new testing costs.

- *Maintaining tradability:* The change in procedure of standard conformity assessment leads the way for an organizational change within the industry. It may result in the loss of employment mainly in rural areas, where more than 85% of the window manufacturers are located. Furthermore, the main goal of EU policy, increasing the tradability of building products and competitiveness of SMEs in the EU, will not easily be achieved by introducing the CE-mark for windows. (CEC, 2003).

ii. Strategic and Social Concerns

- *SME learning*: Information produced during manufacturing activities becomes a part of organizational knowledge. However, in case of window CE-performances the significant amount of information is created not only in workshop but also in testing laboratories. Often this valuable information asset in terms of performance objectives or component influences on performances is not transferred to the knowledge of manufacturer but remains as the expertise of testing technician. The information is lost and not stored in a structured way to make it possible to be reused. This blocks the way for innovative practices. IT is a development of tool for ensuring formalized knowledge and provides the means to carry this structured knowledge to the manufacturers.

- *Dependency on brand names and local information*: Use of extended shared-ITT is based on searching for similarities of different products to assess the conformity of a new window based on existing test result. Yet, these efforts are highly fragmented throughout Europe as they are developed by different countries considering only the most common local product typologies. Moreover, they have the risk to decrease the new and innovative product designs as they are based on only certain window configuration data and component brand information with a limited applicability.

4. Modelling Approach; Window CE Performance Assessment

Based on the analysis of above concerns and recognizing the window manufacturing characteristics, the model for meeting CE performance assessment is presented in this part. The aim in adopting a modelling approach for CE assessment is to consider individual customer requirements through product flexibility without compromising on cost, quality, and customer responsiveness. To achieve these goals the model elaborates the use of information that is gathered both in manufacturer’s workshop and test laboratories; enhances knowledge capture, reuse and transfer; support engineering analysis for CE performance assessment and enhances product diversity and innovation.

The terminology for window assembly and CE marking are vague or differ among countries due building traditions, type of materials and methods used. The challenge is to build an ontology that is consistent, unambiguous, computer interoperable that provides means to reuse and share knowledge. Ontology-models (Chandeskaran and Jossephson, 2000) are deployed in order to improve knowledge capturing that is embedded both in product specifications and CE performance assessment standards. The model defines concepts, terminologies and relationships to provide a general semantic framework for the window manufacturing and CE mark providing hierarchies and definition of the concepts identifying the most relevant information. The models are presented in a clear knowledge representation language, to give them well-defined formal semantics. UML (Booch *et al*., 2005) is used to represent domain specific concepts for its ease of understand and interact between domain experts.

Table 1: Modelling Basis and Industry Concerns

Concern	Need	Model Concept	Fundamentals of Model
Product diversity	Enhance	Structural Model Behaviour Models	knowledge capture and reuse; engineering analysis
Extensive testing	Decrease	Behaviour Models	engineering analysis
Maintaining tradability	Enhance	Structural Model Behaviour Models	knowledge reuse; engineering analysis
SME learning	Enhance	Structural Model Behaviour Models	knowledge capture, reuse and transfer; engineering analysis
Dependency on brand names and local information	Decrease	Behaviour Models	engineering analysis

Geometric product modelling has been the main focus of many modelling approaches in CAD, CAM applications. Although, geometric information is a starting point in any modelling effort, a model for conformity assessment requires more than physical and geometric representation. Many other types of knowledge about the processes of performance assessment are modelled. A generic representational framework combining all product and CE performance assessment information is provided representing structural, functional and behavioural constraints as shown in Table 1. Basically, the window structural model captures the terminology, component and sub-component properties of a window and provides the part-whole relations between them. Hence, the product information is coded into structural model to reuse and transfer for different model processes. Behaviour model contains the abstract classes for performances and it is the numerical component of the assessment which is based on engineering analysis on relevant fields of performance characteristics. The link between the two is provided by functional mapping based on expert opinions and existing knowledge in tabular format. The rest of this section is organized to define the components of performance assessment model developed for windows to achieve these goals.

4.1 Window Structural Model

The architecture of a window assembly is represented in the model with aggregation and generalization relations. A window is usually composed of different modules that satisfy different function requirements corresponding to different CE performance characteristics. These modules can be further disassembled into sub-modules and parts. This process continues until no branches of the assembly structure can be further decomposed.

The generic model specifies the components which will be included in a window design, their properties and interactions with the description of their function from which causal and functional explanation can be inferred. This view also encapsulates the information that defines the components and window as a whole determined in the design stage (e.g. dimensions, location, and material type). However, any window configuration may or may not have some of the components or sub-components. This is depicted by aggregation relations on each relation.

As shown in Figure 1 any window must have a fixed frame which provides the structural integrity of the window and connects it to the façade wall. Based on the functional requirements and the geometry various components such as casement and filling are then fixed to the frame, composing the whole window unit. Casement is a component which itself is an aggregation of many other components and sub-components. It is a single assembly of stiles and rails made into a frame for holding glass, available in a variety of sliding or hinged models and hardware satisfies the movement of the casement where necessary.

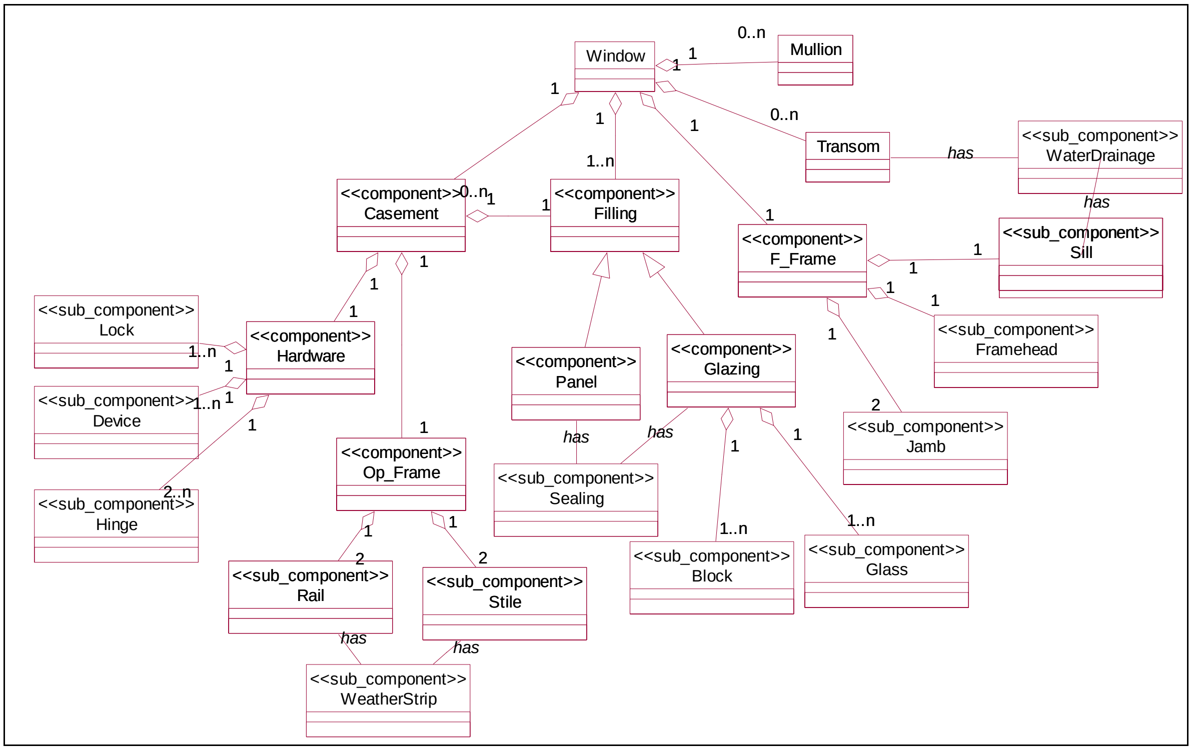


Figure 1: Generic Structural View of Window Assembly

4.2 Structural – Functional Mapping

The mapping stage of the modelling outlines the information about casual links between window components and performance characteristics. Correlations are used to describe the observed casual links between instances of two events (e.g. casement with an operation style resulting in low WT performance class). Strong correlation does often warrant further investigation to determine causation. Table 1 characterizes that if a property of any component is defined to be correlated with a specific performance then a change in the value of that property will influence the value of the performance that it is correlated. The (+) sign denotes high correlation, (0) sign denotes moderate correlation, and (-) sign denotes weak or no correlation. Behaviour model concentrates on highly correlated components and properties of windows to develop causal relations and performance assessment procedures. Model provides casual knowledge in various levels of detail. In addition to component-performance mapping in Table 2, the detailed information is included with parameter-performance mapping for behaviour modelling.

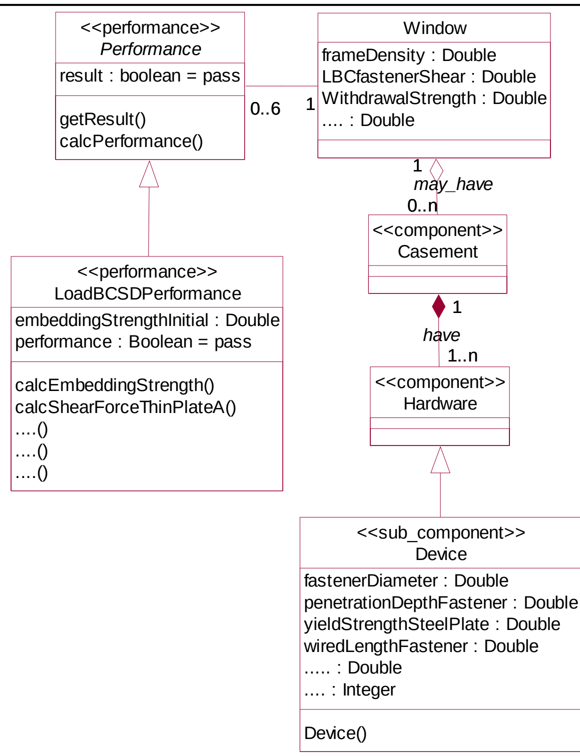
Table 2: Correlation Table for Major Window Components and Performance Characteristics

Window	TT	SI	AP	WT	RWL	LBCSD
Frame	+	o	o	+	+	o
Filling	+	+	-	-	o	-
Casement	+	+	+	+	o	+
Hardware	-	-	+	+	+	+

4.3 Behaviour Model

The scope of the terminology for functional and behavioural properties of a product is strictly dependent on the viewpoint of the product model (Coulibaly *et al.*, 2007, Chandeskaran and Jossephson, 2000) and is also a well studied concept in building information modelling (Nederveen, 1992). In the current research, behaviour is defined as the change of window component variables and the way this change occurs during assessment of certain CE performance characteristics. Behaviour model is composed of six different views of the window for each different performance characteristics in the scope of CE performance assessment.

Behaviour model is the numerical component of the assessment model which evaluates the corresponding performance result of the window. Physical phenomena like RWL, LBCSD, SI and TT are described using mathematical models. The calculations for these performances are derived from the methods in the relevant standard or extended from existing engineering literature. Behaviour descriptions of a window configuration for WT and AP are compiled as graphic representations and fault trees, and probabilistic casual network models. The calculation is based on input values determined by the window design and boundary conditions which are formulated in the model based on the procedures defined in test standards. Numerical or qualitative descriptions computed as the result of behavioural model provide a basis for describing system state that are relevant under specified conditions.



(a)

Figure 2a: Performance View for LBCSD

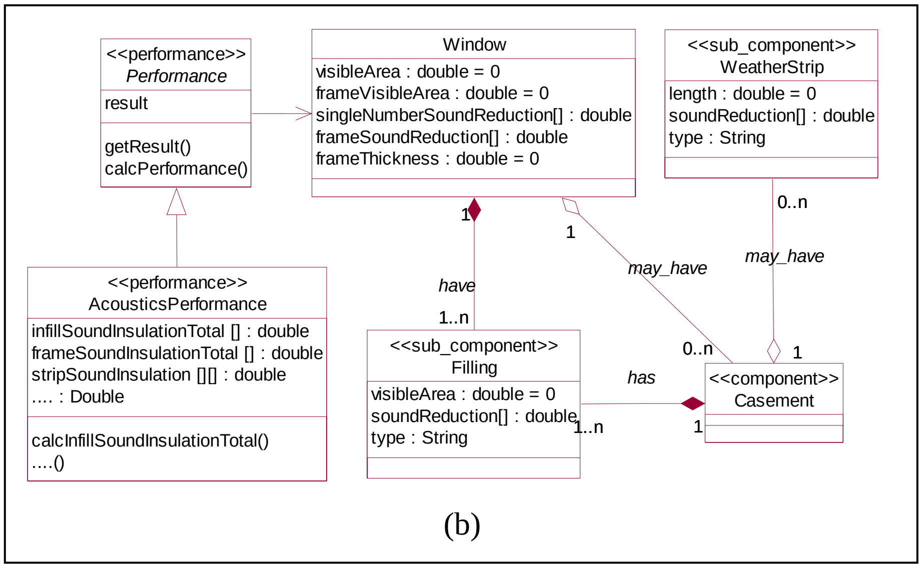


Figure 2b: Performance View for SI

For window product models two cases are possible: first, a set of components serving specific performance criteria but irrelevant for others; second, a set of components relevant to a set of performance criteria with different physical properties. Figure 2 shows two different views from LBCSD and SI. Hence, the physical phenomenon are significantly different, the components and properties included in the views are also different.

In terms of CE mark assessment certain groups of products are clustered that have same procedural behaviour regarding to their performance. These groups of windows are therefore classified as product families and the behaviour of each product family is identified from the others depending on the engineering knowledge in the numerical model for each performance characteristics. A product family is comprised of a group of similar components that have generic function patterns with minor other differences (e.g. fixed versus unfixed casement). This helps to explicitly define the functional configuration knowledge to the behaviour model.

5. Concluding Remarks

Harmonization and existing conformity assessment systems triggers a number of potentials as well as some draw backs on economic, technical and strategic interests especially for customized and small series products such as windows. Trading windows under the new product specification can lead to a strong product diversification due to different building legislations, building processes and building traditions in different countries which may bring more testing cost to manufacturers.

The approach presented in this research is to develop structural and behaviour models for windows for evaluating CE performance, providing attention to standardized procedures and harmonized descriptions of terminology. The behavioural models provide a support to the construction industry to decrease the amount of time and money allocated for physical testing of building products. Analytical models provide information about system behaviour which can be used in new product design or prototype development and adjusting the trade off between maximizing the product performance and minimizing the testing cost to enhance product diversity and maintain tradability.

The SMEs require a high degree of know-how in order to produce new products that can meet the EU-requirements and introduce them to market in a time and cost efficient approach. There are probably great opportunities in the window industry for production of more analysis leading to mass customization using flexible manufacturing techniques and automation on a scale not at present achieved. The development of IT applications in design like on-line access to product databases, online procurement of components, and object oriented design should promote market surveillance and international trade for windows. Therefore, it is essential to capture the domain knowledge and use structural models as a tool to share and reuse it. Structural models enhance the information kept in a formal way and to be transferred to computerized tools.

Furthermore, use of information technologies is not limited to computerized utilization of analytical models. It is remarkable that utilization of CE-performance assessment through a world-wide-web based tool may enhance establishing marketing success and competitive advantage as the manufacturer can easily reach the models without the need of analytical background. This can preserve the market diversity and sustainability in existence of common CE mark for even SMEs.

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