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Abstract: Global competitiveness has challenged manufacturing industry to rationalize different ways of bringing to the market new products in a short lead-time with competitive prices, high quality, and customization. Modern Product Development Process (PDP) has been requiring simultaneously collaboration of multiple groups, exchanging information from multiple perspectives within and across enterprise boundaries. However, semantic interoperability issues (misinterpretation and mistakes) in view of the information heterogeneity from multiple perspectives and their relationships. This research proposes a semantic reconciliation view to support the interoperable information relationships in product design and manufacturing. This view is part of the conceptual framework of an Interoperable Product Design and Manufacturing System (IPDMS). The semantic reconciliation method uses three approaches (Adjustment Context, Ontology Intersection, and Semantic Alignment) to provide support for the semantic information relationships across the product design and manufacturing. The method is applied in a rotational thin-wall plastic injected design and manufacturing and evaluated through the development of semantic rules responsible for the information mapping of sharing, conversion and translation. This semantic rules were modeled in Semantic Web Rule Language (SWRL) supported by Web Ontology Languages (OWL). Sequentially, the potential benefits and limitation of the method was discussed, contributing to the semantic information interoperability during the development of complex products.

*Keywords:* Modern Product Development Process, Semantic Information Interoperability, Multiple Domains, Formal Rules, Ontology.

## 1. INTRODUCTION

The modern manufacturing industry has been challenged to rationalise different ways of offering to the market new products in a short lead-time with competitive prices while ensuring higher quality levels and customization. Product Development Process is used to speed up the new product launching and market expansion while fulfilling the customer's demand and desires.

Product Development Process has a set of multidisciplinary activities structured to transform market opportunities, customer's needs and technological constraints in products (Pereira and Canciglieri Junior, 2016). During the Product Development Process, experts from different fields (mechanical, electrical, software, business) work together and share information, knowledge and resources to solve product development issues (Penciuc et al., 2014). Thousands of heterogeneous information are shared simultaneously by different groups within and across institutional boundaries using different formats and models to represent the product in development.

These issues have encouraged the improvement of Product Data Management (PDM) and more recently, the Product Lifecycle Management (PLM). Both PDM and PLM manage the product data during the whole product lifecycle (Bruun et al., 2015). Although PLM has a holistic view of the whole phases of product lifecycle, it does not consider the meaning associated to each captured information and their relationships across different phases of Product Development Process (Chungoora et al., 2013). In this way, misinterpretation and mistakes has been identified during the product development since different taxonomies for representing the product are used for the developers.

This is a typical semantic interoperability problem that concerns the concepts definition and semantic supporting for the relationships between data and knowledge models. Interoperability is defined "as the capacity of two or more systems to share information and to use the information that has been shared (IEEE, 1990).

Multiple resourceful efforts have been promoted to formalise information, from product and manufacturing models, in order to define common structure information. International standards have been providing basis for the product information relationships, such as STEP PLCS (ISO 10303). Related works (Liao et al., 2016; Palmer *et al.*, 2016; Panetto, Dassisti and Tursi, 2012) show that there is a trend to explore the use of Ontology concept, through Web Ontology Language (OWL), to model the knowledge. However, a significant problem is to share information from multiple domains across different phases of product development process once it is necessary to explore effective and technical methods for semantically map information.

In order to cope with this challenge, this paper proposes a semantic reconciliation view to support the interoperable information relationships across the product design and manufacturing. This view is based on well-defined semantic rules in order to establish semantic mapping of sharing, conversion or translation information. These formal, well-defined relationships ensure the correct information and knowledge exchange across the product development. Therefore, the main contributions of this paper are highlighted as (i) advancement of the collaborative and integrated product development process; and (ii) interoperability between heterogeneous information from multiple domains.

Besides this introductory section, the Section 2 presents a technological background in terms of ontology-driven interoperability and semantic mapping. Section 3 proposes the semantic reconciliation method to support the formal interoperable relationships in product design and manufacturing, and section 4 evaluates the application of the proposed method in a test case. Finally, the section 5 concludes and presents perspectives for the research continuation.

## 2. TECHNOLOGICAL BACKGROUND

Product Development Process is responsible for transforming customer's needs, market opportunities and technological constraints in a product (Singh, 2002). It has a set of transdisciplinary-structured activities that required the involvement of specialists with multiple viewpoints (Pereira and Canciglieiri Junior, 2016). Product Development Process is complex because heterogeneous groups must simultaneously share information from multiple domains. Although Product Development Process has a well-defined structure for the activities of the product development, it does not cope with the relationship of this information across its different phases. Misinterpretation and mistakes has been identified alongside the product design and manufacturing once the interaction of multiple groups is more intense in these phases (Szejka et al., 2016a).

Interoperability problems occurs when the meaning associated to the captured information is not effectively shared across different phases without losing the meaning associated to it (Chungoora et al. 2013). The alternatives to overcome the semantic obstacles are to create integrated solutions by defining common information models and their relationships (Canciglieri Junior and Young, 2010).

Ontology has attracted a lot of attention for the development of shared representations (Danjou, Duigou and Eynard, 2016; Naeem et al., 2014 and Barbau et al., 2012). It has been observed that the ability for sharing semantics across these representations is dependent on the degree of formality or logical expressiveness supported by ontological formalisms. However, it has to be appreciated that even in the deployment of ontology-based methods, semantic heterogeneity is unavoidable and for this reason, methods for ontology mapping are being developed to reconcile the semantics between ontologies that need to interoperate (Fahad et al., 2010). Although ontologies create semantic formalisms, an expressive problem is how to work with multiple ontologies of multiple domains to provide effective mapping information across them (Nagahanumaiah and Ravi, 2008). Ontology mapping has been the key point to tackle semantic heterogeneity issues across ontologies, intending to promote semantic interoperability. Mapping is an important and critical operation in traditional applications such as (i) information integration; (ii) query answering; and (iii) data transformation.

Ontology mapping is the process of finding correspondences between the concepts of two ontologies. If two concepts correspond, then they mean the same thing or closely related things. Currently, the mapping process is considered as a promise to solve the heterogeneity problem between ontologies since it attempts to find correspondences between semantically related entities that belong to different ontologies. It takes as input two ontologies, each one consisting of a set of components (classes, instances, properties, rules, axioms, etc.), and determines as output the similarity matching.

Several categories of ontology mapping methods have been suggested by Shvaiko and Euzenat, (2013), but there is a common consensus over the types of methods that can be applied. The main types are (i) Alignment/Sharing; (ii) Conversion; and (iii) Transformation/Translation. Alignment or Sharing is the process of reaching global compatibility between two or more concepts or instances. Conversion is the process of changing the representation formalism of the ontology based on a mathematic equation; chemical composition; etc., while preserving its semantic. Transformation is the process of changing the semantics of the concepts and probably the representation formalism, with the intent to make new concepts or instances suitable for different purpose.

Hence, this research addresses the structure of the relationship formalisation in product design and manufacturing information based on ontologies and mapping ontologies to extract and enrich information to support the information exchange across PDP phases in a transdisciplinary environment. Related works (Belkadi et al. 2012; Kim, Manley and Yang, 2006) explore the use of ontology formalised in Web Ontology Language (OWL) and the semantic rules to infer the semantic mapping modelled in Semantic Web Rule Languages. The integration between OWL and SWRL infers the semantic mapping in order to establish the correct information relationships across multiple domains and Product Development Process.

## 3. SEMANTIC RECONCILIATION VIEW TO SUPPORT THE INFORMATION INTEROPERABILITY IN PRODUCT DESIGN AND MANUFACTURING

Product Design and Manufacturing are two phases of Product Development Process, which are responsible to transform the customer's needs and technical constraints in tangible (physical product) or intangible (service or software) products. As presented in the section 2, there are several limitations and issues related to data misinterpretation and mistakes. This is a typical semantic interoperability problem that increases costs and impairs further development phases.

The concept of semantic reconciliation is considered as a solution to define the relationships of heterogeneous information, inferring the semantic mapping of sharing, conversion and translation across the Product Design and Manufacturing. This approach is part of an Interoperable Product Design and Manufacturing System (IPDMS) proposed by Szejka (Szejka et al., 2016a) which provides support to information exchange in a semantic interoperable manner by a computer environment.

*3.1 Interoperable Product Design and Manufacturing System Overview*

The Interoperable Product Design and Manufacturing System uses well-defined semantic core concepts in multiple domains to simultaneously instantiate information in the application domain view, according to the specific product information and technological limitations. In addition, semantic relationships can be established between the instantiated information, allowing their semantic mapping of translation, conversion and sharing between different phases of product design and manufacturing. The IPDMS architecture is presented in Fig. 1, explored in (Szejka et al., 2016a and Szejka, 2016).

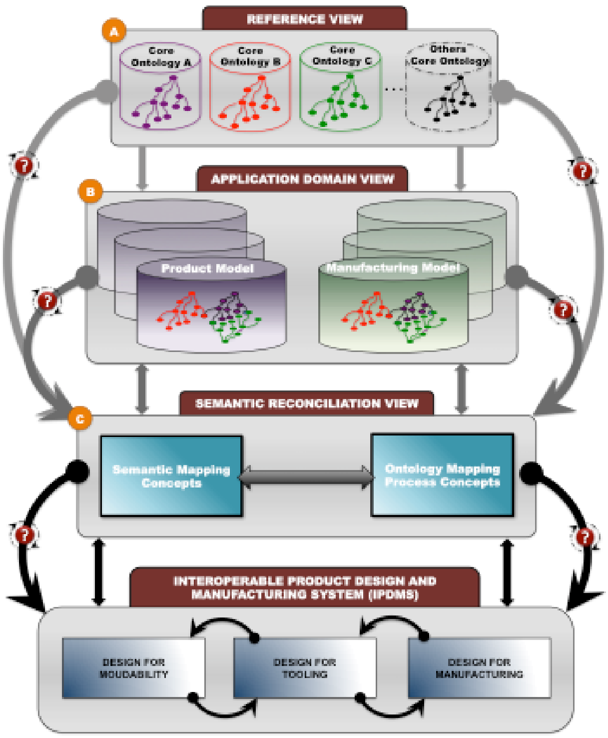



Fig. 1 Interoperable Product Design and Manufacturing System Architecture (Szejka, 2016).

- **Reference View** (Detail A of Fig. 1) – This view collects and structures concepts from different fields to formally represent, in a elementary form, the product design and manufacturing concepts from different perspectives. The concepts are modelled in common logic-based formalism, Web Ontology Language (OWL), named core ontologies. Reference View can have Design Core, Manufacturing Core, Material Core, etc. The Foundation View Formalization was explored in (Szejka et al., 2016b).
- **Application Domain View** (Detail B of Fig. 1) – This view represents the specialisation process of the core concepts from Foundation View into Applied Concepts according to the information about the product and the semantic reconciliation process. The information from the product is instantiated in the core concepts respecting the semantic rules, originating an interoperable environment with information in a common language.
- **Semantic Reconciliation View** (Detail C of Fig. 1) – This view establishes the semantic rules for defining the relationships of heterogeneous information, inferring the semantic mapping of sharing, conversion or translation across different phases of Product Development Process. The semantic rules to constrain the relationships can be intra-contexts (in a single domain) or inter-contexts (multiple domains). When the logic conditions are true, the semantic mapping of share, convert or translate are inferred and when the logic conditions are false, the semantic mapping of inconsistency is inferred.

*3.2 Semantic Reconciliation View Concept*

Semantic Reconciliation View explores relevant applied ontology techniques enabling the reconciliation of domain semantics. The techniques work segments of known ontology matching methods such as (i) the computation of contexts for domain ontologies (Stumme and Maedche, 2001); (ii) ontology intersection (Mecca et al., 2015; Shvaiko and Euzenat, 2013; Ehrig and Sure, 2004) and (iii) semantic alignment. Fig. 2 presents the concepts involved to establish the semantic reconciliation in the IPDMS.

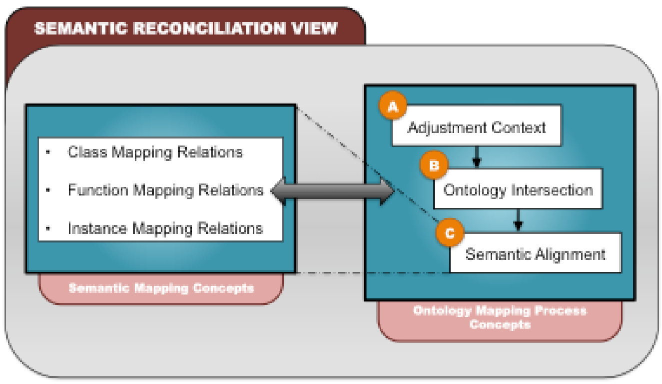



Fig. 2. Semantic Reconciliation View Architecture.

- **Adjustment Context** (Detail A of Fig. 2) – The adjustment context is the first phase of semantic reconciliation and executes the alignment of concepts with the specific domain application, i.e. the context is aligned according to the product that will be developed.

- **Ontology Intersection** (Detail B of Fig. 2) – The ontology intersection copes with the intersection of multiple domains. In this process, the domains of ontology are preserved enabling the semantic mapping in order to ensure the correct information relationship. The classes' hierarchy, object, and data properties are preserved in this process, ensuring the structure of information from the core ontologies.
- **Semantic Alignment** (Detail C of Fig. 2) – The semantic alignment is the heart of the semantic reconciliation view once it allows the establishment of the relationships with the information from multiple perspectives. The alignment process is enabled by the specialised semantic mapping (concepts and/or instances) ontology in the Application Domain View.

### *3.3 Adjustment Context in Semantic Reconciliation View*

The adjustment context procedure is important because of the semantic alignment process, which takes place later on ontology mapping, and involves semantic mapping concepts based on the predefined contexts. The process of context adjustment is straightforward and only requires the substitution of the domain contexts names.

The first phases of Product Design and Manufacturing are dedicated to the design for mouldability. Design for Mouldability is dependent of different information, for example, material properties that can impact directly in different products definition/specification. Thus, the Material concepts must be inserted in the context of design for mouldability as well as the Product Mouldability Concepts in order to structure the information. Fig. 3 represents an example of core contexts adjust to Specific Domain Context.

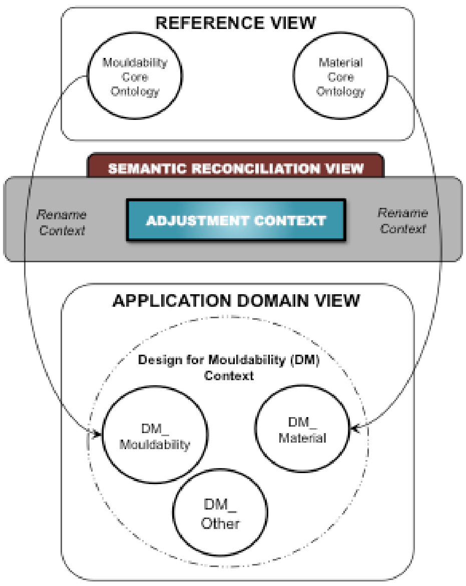



Fig. 3 Adjusting Core Context to Specific Domain Context.

### *3.4 Ontology Intersection in Semantic Reconciliation View*

Ontology intersection gathers multiple ontologies related to different contexts in a single ontology that will be enriched with information about the product. Figure 4 illustrates the intersection process with two core ontologies. The simple intersection process is applied to the ontology "A" and the ontology "B", resulting in the ontology "AB" (a central concept that integrates both ontologies). New information and knowledge can be added in order to enrich the semantic interoperability across the product design and manufacturing. However, the classes' hierarchy, object properties and data properties are preserved in this process, ensuring the structure of information from the core ontologies.

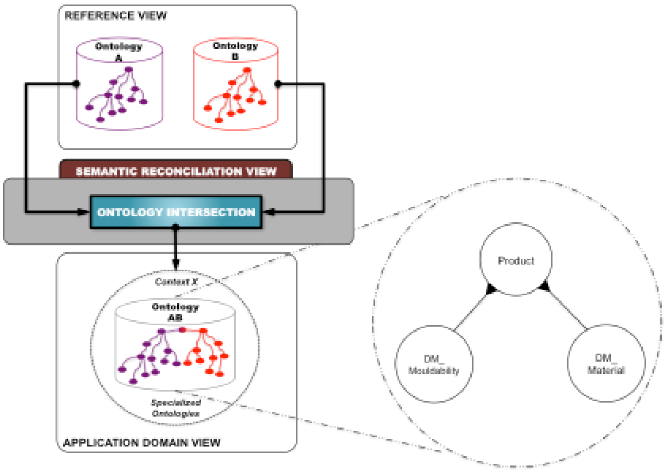



Fig. 4 Ontology Intersection Process.

### *3.5 Semantic Alignment Process in Semantic Reconciliation View*

The alignment process is enabled by specialised semantic mapping (concepts and/or instance) ontologies in the Application Domain View, as illustrated in Fig. 5.

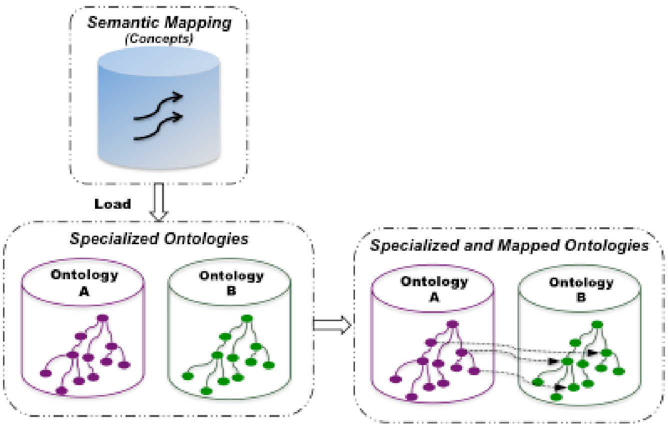



Fig. 5 Semantic Alignment Process.

The relations in the semantic alignment process must satisfy the logical conditions. This research considers three logical conditions for the information relationships: (i) information sharing; (ii) information conversion; and (iii) information translation. The information sharing has the function to exchange information with the same unit scale and/or same meaning, i.e., it establishes a relationship of equivalence, without any additional information. One information sharing example is the exchange of the material name (material_name) between the "*DM_Mouldability*" and "*DM_Material*".

The information unit conversion relates information based on strict rules, for example, the unit conversion mathematic equation (1) is applied if dimension information in millimetres is exchanged with the dimension information in inches, ensuring the correct information exchanging.

$$f(x)(in) = \frac{x(mm)}{25{,}4} \qquad (1)$$

Where: "f(x)" is the solution of mathematic conversion from millimetre to inches and "x" is the variable in millimetres.

Finally, the last logical condition is the information translation. This one is the most important and complex condition of the semantic alignment. The information translation requires the addition or comparison with other information in order to generate the results. One information translation example is the information exchange between the product profiles from conceptual design phase and tooling design phase. This translation requires extra information, for example from material, in order to define the correct profile of the tooling.

The semantic alignment has two distinct conditions as follows: (i) the intra-context semantic alignment, i.e., the information is exchanged in the same context, for example, the information exchange in the conceptual design phase; (ii) the inter-context semantic alignment, when the information is exchanged across contexts, for example, between conceptual design phase and tooling design phase or tooling design phase and manufacturing design phase.

Semantic Alignment is supported by the semantic mapping process, which uses Semantic Web Rule Language (SWRL) approach to support the relationships. SWRL is an expressive OWL-based rule language that allows users to write rules that can be expressed in terms of OWL 2 concepts to provide more powerful deductive reasoning capabilities.

## 4. APPLYING THE CONCEPTS OF SEMANTIC RECONCILIATION IN ROTATIONAL THIN-WALL PLASTIC INJECTED PRODUCTS

Injection moulding is a huge area of knowledge that comprehends specialised sub-areas and has offered to opportunities to explore, in a multiple-perspective approach, the diverseness in the issues related to the plastic part moulding and manufacturing. Plastic injection moulding products is a problematic and pricey process to industries since several variables and implicit information are involved during the product manufacturing and must be considered concomitantly. The shrinkage rate is an example of the process complexity as each material has a different rate and impacts directly the product mouldability design.

In this context, the research application focused on a specific rotational thin-wall injected plastic product, taking into account the information interoperability across product design and manufacturing and their relationships. The product is a thermal cup with 200 millilitres and manufactured in Polystyrene "PSC 1160", which has shrinkage factor equal to 0.0055.

The product information exchanging occurs in single phases such as: (i) Design for Mouldability phase (Detail A of Fig. 6) and (ii) Design for Tooling phase (Cavity Insert Design – Detail B of Fig. 6 and Core Insert Design – Detail C of Fig. 6); as well as across multiple phases such as (iii) Design for Mouldability and Design for Tooling Phases.

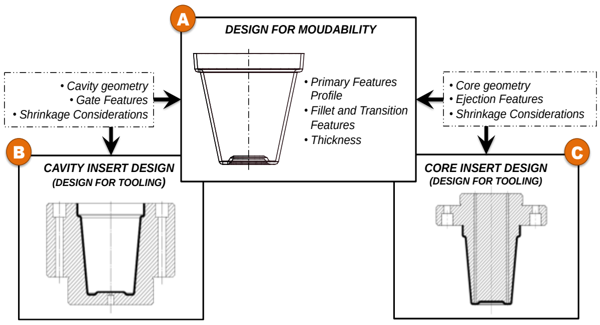



Fig. 6 Information relationship in Design for Mouldability and Design for Tooling.

In order to support the information relationship in a semantically interoperable manner, the semantic reconciliation view concepts were applied following the structure proposed in the IPDMS. Firstly, it is necessary adjust the context (as shown in section 3.1) in order to define the core concepts to support the data structure of plastic injected products in the reference view. In the research of (Szejka, 2016), two core ontologies to support the rotational thin-wall plastic injected products were proposed as follow: (i) Rotational Mouldability Core Ontology (Fig. 7); and (ii) Mould Design Core Ontology (Fig. 11). The concepts directly related to the Product Mouldability phase and Product Tooling Design phase were explored for this application.

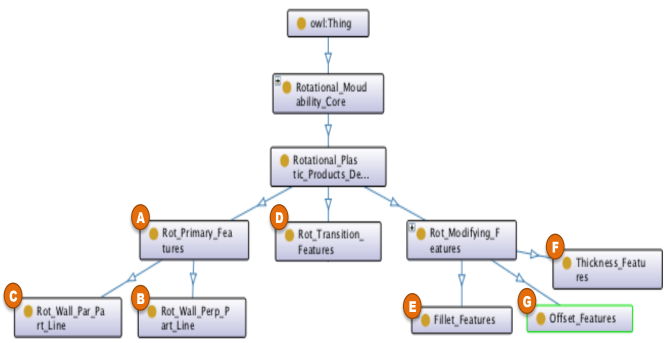



Fig. 7 Rotational Mouldability Core Ontology (Szejka, 2016).

The thermal cup is represented based on mouldability features that are stated with characteristic or information about the product. The mouldability features about the product are composed by rotational primary features (Detail A of Fig. 7) and rotational transition features (Detail D of Fig. 7). The reference line in the injection moulding process is the parting line once it defines the mould limit between the cavity insert and core insert. In this way, the Rotational Primary features are oriented according to the parting line where one profile can be parallel profile to the parting line (Detail C of Fig. 7) or perpendicular profile to the parting line (Detail B of Fig. 7). Thus, it is necessary define the sharing relationship between Rotational Primary features and parallel or perpendicular profile to the parting line. Sharing and conversion mapping are inferred with the concepts of a single ontology. In these cases are not necessary to develop the intersection ontology process, only the semantic alignment (as shown in section 3.3) through the semantic rules. Fig. 8 demonstrates the relationship of these variables through semantic rules (rule 1 to rule 3) in SWRL.

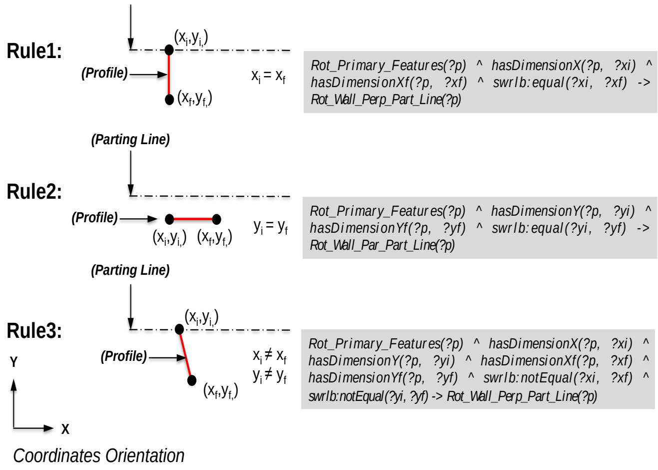


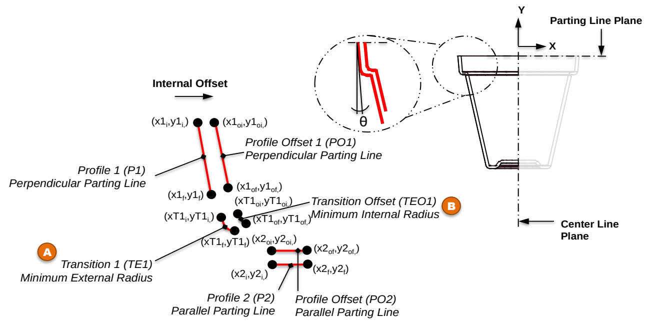

Fig. 8 Semantic Mapping Rules of Sharing to the Primary Features.

Transition features (Detail D of Fig. 7) are responsible to connect two primary features. Their value must be in accordance with the minimum acceptable fillet value (Detail E of Fig. 7) otherwise, it is not possible to execute the moulding injection process. The minimum fillet has two distinct values: (i) minimum fillet for the external profiles (Detail A of Fig. 9) or (ii) minimum fillet for the internal profiles (Detail B of Fig. 9). Minimum external fillet follows the equation (2) and minimum internal fillet follows the equation (3). In this context, the rules 4 and 5 demonstrate semantic mapping of conversion to define the transition features and any inconsistency in this process is identified by the rule 6. These rules are shown in Fig. 9.

$$\min external\ fillet = \frac{3}{2} * thickness \tag{2}$$

$$\min internal\ fillet = \frac{1}{2} * thickness \tag{3}$$

Thickness features (Detail F of Fig. 7) and Offset features (Detail G of Fig. 7) are equivalent terms, where the offset is a technical term of design and manufacturing domain and thickness is a common term of material and other domains. So, sharing information mapping between these two concepts is essential in order to avoid any mistakes, as shown in Fig. 10.




**Rule4:** *Offset_Features(?p) ^ hasValue (?p,?q) ^ Fillet_Features(?a) ^ hasValue (?a,?b)^swrlb:multiply(?b,?q,0.5)-> hasConversion(?a,?p)*

**Rule5:** *Offset_Features(?p) ^ hasValue (?p,?q) ^ Fillet_Features(?a) ^ hasValue (?a,?b)^swrlb:multiply(?b,?q,1.5)-> hasConversion(?a,?p)*

**Rule6:** *Fillet_Features(?a) ^ hasConcistency (?a,?c) ^ offset_Features(?b) ^ swrlb:notEqual(?c,?b) -> hasInconsistency(?a,?b)*

Fig. 9 Semantic mapping rules of conversion to infer the transition features.

**Rule7:** *Thickness_Features(?p) -> Offset_Features(?p)*

Fig. 10 Semantic mapping rule of equivalence.

The relationship between design for mouldability and design for tooling is considered a translation process because it is necessary to consider information from multiple domains, for example, information about the tooling design, offset direction and shrinkage factor. Fig. 11 illustrates the Rotational Mould Design Core Ontology that is the data structure of the tooling design. The impression system, which is responsible to define the shape of the product during the moulding injection process, is divided in Rotational Cavity Insert (Detail A of Fig. 11) and Rotational Core Insert (Detail B of Fig. 11).

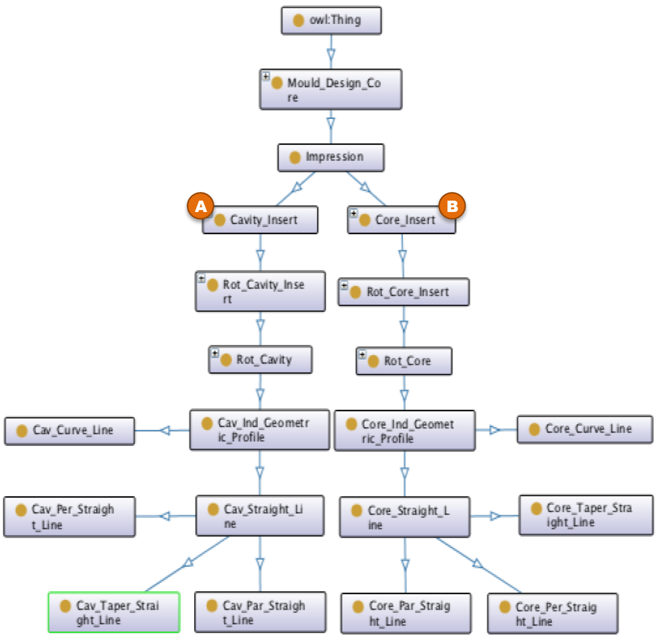



Fig. 11 Rotational Mould Design Core Ontology (Szejka, 2016).

Offset direction defines the core or cavity insert profile of the mould, for instance, if the offset is to the internal direction the external product profile defines the cavity insert and the internal product profile defines the core insert, as shown in Fig. 12.

Shrinkage occurs because polymers density varies from the processing temperature to the ambient temperature. The product is going to wrap upon ejection from the mould or crack with the external load during the extraction if the shrinkage factor is not considered. Thus, the product data from mouldability design to be translated to tooling design must follow the equation (4).

$$tool\_coord = product\_coord * (1 + shrinkage\_factor) \quad (4)$$

In this context, Fig. 13 depicts the translation process in the geometric profile when the offset is in the internal direction. Detail A of Fig. 13 presents the translation process of the external profile of the product to design the cavity insert profile. Detail B of Fig. 13 presents the translation process of the internal profile of the product to design the core insert profile.

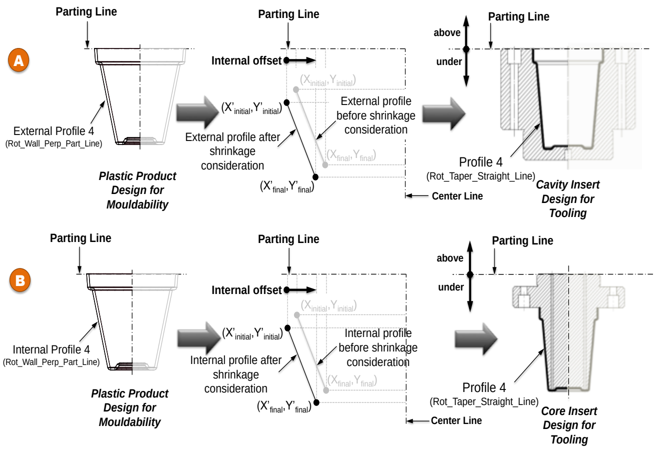



Fig. 12 Demonstration of translation from Mouldability Design into Tooling Design.

The translation process requires the ontology intersection between rotational mouldability core ontology and rotational mould design core ontology, according to the semantic reconciliation view process, in order to define the semantic rules for mapping the translation. The ontology intersection process conserves the concepts, instances, data properties and object properties. If there are any information conflicts, they are solving by the designers or engineers. Fig. 14 depicts the intersection process executed between the Rotational Mouldability Ontology and Rotational Mould Design Ontology.

After the ontology intersection, the semantic rules for mapping the information translation between these two ontologies can be executed. The semantic relationship occurs between the Rotational Primary Features and Rotational Cavity Insert Straight Line or Rotational Core Insert Straight Line according to the offset direction and shrinkage factor. The semantic rule for translation mapping of the Rotational Primary Features into Rotational core straight line is presented in the rule 8 of Fig. 14, when the offset is to the internal direction and the rule 9 of Fig. 14 presents the semantic rule for translation mapping of the Rotational Primary Features into Rotational cavity straight line.

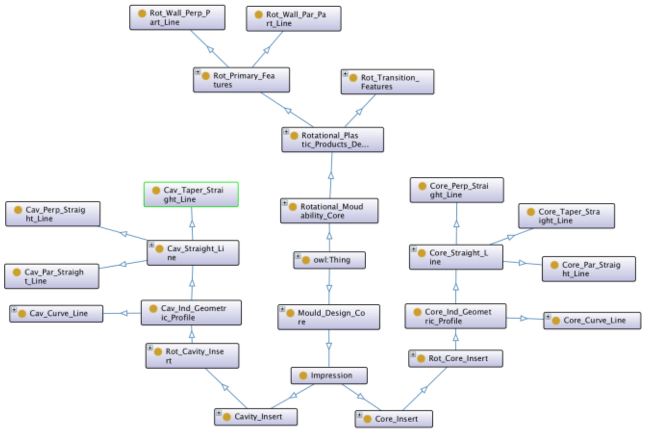


Fig. 13 Results of ontology intersection.

**Rule8:** *Rot_Primary_Features(?p) ^ hasDimensionX(?p, ?xi) ^ hasDimensionY(?p, ?yi) ^ hasDimensionXf(?p, ?xf) ^ hasDimensionYf(?p, ?yf) ^ Rot_Primary_Features(?q) ^ hasDimensionXio(?q, ?xio) ^ hasDimensionYio(?q, ?yio) ^ hasDimensionXfo(?q, ?xfo) ^ hasDimensionYfo(?q, ?yfo) ^ Cav_Straight_Line(?u) ^ hasDimensionX(?u, ?xci) ^ hasDimensionY(?u, ?yci) ^ hasDimensionXf(?u, ?xcf) ^ hasDimensionYf(?u, ?ycf) ^ Plastic_Product_Material(?v) ^ hasShrinkageFactor(?v, ?SKF) ^ swrlb:greaterThanOrEqual(?xi,?xio) ^ swrlb:greaterThanOrEqual (?xf,?xfo) ^ swrlb:multiply (?xci, ?xi, ?SKF) ^ swrlb:multiply (?yci, ?yi, ?SKF ^ swrlb:multiply(?xcf, ?xf, ?SKF) ^ swrlb:multiply(?ycf, ?yf, ?SKF) -> hasTranslation (?u, ?p)*

**Rule9:** *Rot_Primary_Features(?p) ^ hasDimensionX(?p, ?xi) ^ hasDimensionY(?p, ?yi) ^ hasDimensionXf(?p, ?xf) ^ hasDimensionYf(?p, ?yf) ^ Rot_Primary_Features(?q) ^ hasDimensionXio(?q, ?xio) ^ hasDimensionYio(?q, ?yio) ^ hasDimensionXfo(?q, ?xfo) ^ hasDimensionYfo(?q, ?yfo) ^ Core_Straight_Line(?u) ^ hasDimensionX(?u, ?xcoi) ^ hasDimensionY(?u, ?ycoi) ^ hasDimensionXf(?u, ?xcof) ^ hasDimensionYf(?u, ?ycof) ^ Plastic_Product_Material(?v) ^ hasShrinkageFactor(?v, ?SKF) ^ swrlb:lesserThanOrEqual(?xi,?xio) ^ swrlb:lesserThanOrEqual (?xf,?xfo) ^ swrlb:multiply (?xcoi, ?xi, ?SKF) ^ swrlb:multiply (?ycoi, ?yi, ?SKF ^ swrlb:multiply(?xcof, ?xf, ?SKF) ^ swrlb:multiply(?ycof, ?yf, ?SKF) -> hasTranslation (?p, ?u)*

Fig. 14 Semantic mapping rules of translation.

## 5. CONCLUSIONS

This paper presented a semantic reconciliation view to support the interoperable information relationships in product design and manufacturing. This method is part of the development of an Interoperable Product Design and Manufacturing System (IPDMS) concept that are able to exchange information from multiple domains across product design and manufacturing in a semantic interoperable manner. IPDMS supports the product developers and engineers, providing structured and formal information as well as inferring automatically information mapping based on the knowledge added to the system.

The semantic reconciliation view uses semantic well-defined rules to infer the relationships of different concepts and instances. The semantic reconciliation method is structured in three parts: (i) Adjustment Context; (ii) Ontology Intersection; and (iii) Semantic Alignment. The last one is the most important once it is responsible for the semantic rules, which according to the logical conditions infers the semantic mappings of information translation, conversion and sharing.

The sharing mapping was defined when two concepts or instances use the same piece of information without any change in it. The conversion mapping was defined when one specific information needs the information of another perspective and the link of this information is a simple mathematical equation. Finally, the translation mapping is similar to the conversion process but requires multiples comparisons from distinct knowledge in order to establish the semantic relationships. The translation process is more complex than information sharing and conversion since the information translation must have knowledge of the relationships between the two distinct perspectives in order to map information from one to another.

The semantic rules were defined using the Semantic Web Rule Language (SWRL) that is applicable and reasonable with ontologies modelled in Web Ontology Language (OWL). Additionally, Pellet reasoner can be used as the inference engine, which is responsible for analysing the logical conditions and creating the inferences. Pellet is a complete OWL-DL reasoner with extensive support for reasoning with individuals and user-defined data types.

This concept has been applied and evaluated in a preliminary test case. The product is a polystyrene cup with thermal conservation properties. The evaluation process demonstrates the potential of the method to support the information exchange between the design for mouldability and design for tooling to avoid misinterpretation and mistakes. To demonstrate the semantic mapping of sharing, conversion and translation, 9 rules were proposed. However, it is necessary to extend this research work in order to evaluate the method with multiple rules and explore more variables simultaneously across multiple phases of the PDP. Additionally, different formalisation languages needs to be evaluate, since SWRL presents a taxonomy with several restrictions that can limited the semantic rule representations.

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