A Knowledge-based Tool for Risk Prevention on Pressure Equipments

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ABSTRACT

Process plants design, construction, and operation of major equipments are ruled by standards and engineering codes, which are intended to assure reliability and safety. In the case of pressure vessels these rules are aimed at guaranteeing the stability under required pressure and temperature conditions. In this paper we exploit the most advanced capabilities of CAD systems, in order to support safety rules compliance of pressure equipments during the design and verification activities. We present a knowledge-based tool supporting the appropriate safety normative since the first stages of the design process of pressure vessels, and the *a posteriori* normative verification required for certification purposes. The knowledge base of the tool has been formalized through the use of ontology.

Keywords: Knowledge-based CAD, Risk analysis, Ontology, Knowledge management.

1. INTRODUCTION

The design of a process plant is a complex activity that usually involves many different disciplines over a long time. The design activity goes through many steps from the original research and development phases, the conceptual and the detailed design process, to the detailed equipment design. Equipments, such as pressure vessels, tanks, reactors, boilers, pumps, and valves have to meet complex safety requirements and criteria. General safety criteria are quite difficult to assess in the design phase. To this aim, in the past decades, professional institutions and trade associations developed engineering codes and standards, which cover the design, the construction and the inspection of a wide range of equipments. Engineering codes on boiler and pressure vessels, low-pressure storage tanks, heat exchangers, steam generators, compressors, pumps, steam and gas turbines are widely applied in process industry, in order to realize safe plant components and to meet the overall plant safety criteria. The use of sound technical codes is highly recommended during the design phase, in order to achieve safety objectives while minimizing the effort and reducing the uncertainty. For this reason, the adoption of appropriate standards and codes for the employment and the maintenance of plant equipments, which operate in a major hazard establishment, is a crucial issue for the assessment of the safety, as required by the "Seveso II Directive" [1]. Designers need to verify the compliance to safety criteria since the very first design phases, in order to avoid errors and time wasting in the next design and approval phases. As required by National and International regulations, technical bodies have to verify quickly the compliance to safety criteria, as soon as they receive the drawings, in order to speed up the approval process.

Nowadays, Computer Aided Design (CAD) systems are worldwide used in every phases of the process plants design. CAD systems, initially developed to handle just geometries, have become sophisticated tools, able to manage all the aspects of an engineering design: shapes, geometric features, functions, constraints, relationships and standards. In last generation CAD systems, geometric rules are not hardcoded in the CAD system software code and may be managed directly by the users: every designer or designers group may adopt his own rules for both regulations defined by normalization bodies, and industrial internal standards resulting from company knowledge and experience.

Rules are the essence and synthesis of knowledge and experiences. The ability to computerize rules efficiently and correctly implies faster and higher quality design and improved budget control. For this reason, whenever CAD systems are able to define and manage rules, they are defined emphatically as "knowledge-based CAD" (KB-CAD). Parts designed by a KB-CAD automatically comply with *a priori* defined rules. In other words, parts designed by a KB-CAD are automatically compliant with the selected code. Furthermore, a KB-CAD may handle parts previously designed, and may verify the compliance with the rules defined also *a posteriori,* highlighting possible incoherencies.

Unfortunately, a KB-CAD is able to manage only detailed and well-defined geometrical rules, but it cannot handle generic, vague or indirect criteria.

In the recent literature the methodology mainly applied to give a formal representation of domains knowledge entails the use of *ontologies*. An ontology is a "specification of a conceptualization" [3], i.e., a representation of the knowledge on a domain of interest, which is often associated with a semantic network structure. Ontologies are employed in order to share, reuse and analyze the knowledge on the represented domain. The definition of ontology includes the definition of a common vocabulary, and the explicit specification of the domain assumptions [9].

Ontologies have been widely used in Engineering, mainly for the sharing/reusing of the domain and functional knowledge. In [8], ontology has been used for the formulation of the problem solving process itself. More recently, several works have been proposed to integrate knowledge at different stages of design by means of ontologies, providing a semantic-based environment for the design process [4].

In [5], ontologies have been defined for HAZard and Operability Analysis (HAZOP) systems to improve risk information reuse in chemical plants; in [10], an ontology has been employed for the semantics-driven simplification of CAD models, applied to the visualization and the design review of large plant models.

In this paper we present a knowledge-based tool supporting both the application of the appropriate safety normative since the first stages of the design process of pressure vessels, and its verification *a posteriori*. The focus of the paper is the formalization of the domain knowledge through the use of ontology. In particular, in the ontology, the current normative the components of a chemical plant must comply with is represented. Specifically, in the starting phase of our work we are focusing on the safety rules for vessels for the storage of under-pressure fluids, according to the Pressure Equipment Directive 97/23/EC (PED) [11]. In Italy, the PED directive is covered by VSR rules [7]. Furthermore, the application supports inspectors in verifying the compliance of pressure vessels CAD models with PED rules. Hazard situations deriving from safety rules violations are semi-automatically identified, thus providing a fundamental capability to support organizations that perform plant safety certifications.

The paper is organized as follows: the first section describes the specified ontology, whereas in section 3 a brief description of the developed prototype system is given. Finally section 4 concludes the paper discussing benefits and limitation of the proposed approach.

2. AN ONTOLOGY FOR PRESSURE EQUIPMENTS

In the following we describe an ontology that represents information about pressure vessels and equipments, which corresponds to the knowledge base of the tool presented in this paper. The ontology has been written in OWL, the Ontology Web Language [12], by using Protégé [13]. The ontology schema is reported in Figure 1, where the main conceptual entities of the domain (e.g., vessel for fluids, vessel components, safety rules, vessel materials, substances, geometric representations, CAD systems, etc.) and their relationships are depicted. For instance, a Vessel For Fluids is designed to contain (*contains*) a set of Substances, and it has a set of vessel Components (*hasComponent*); a Safety rule applies to a (set of) Components (*appliesToComponent*) of a given (set of) Vessel for fluids (*appliesToVessel*) ; a VSR/PED rule is a specific type of Safety Rule.

In Figure 1, rectangles represent the entities, or *concepts*, of the pressure vessels and equipments domain. Concepts correspond to ontology *classes*. An abstract class, i.e., a class for which no instances will be created, is represented by a concept in italic. A concept in the ontology is defined by a set of *properties*, or *slots,* i.e. *attributes*, that describe the main structural characteristics of the concept, and *relationships*, that are defined between the concept and other concepts in the ontology. Figure 1 does not report class attributes, whereas arrows are used to represent relationships between concepts. The resulting graph is directed, i.e., each relationship holds between a source and a destination concept. Given two classes, c_1 and c_2, defined in the ontology, and a relationship *rel* holding between c_1 and c_2, such that c_1 *rel* c_2, then c_1 and c_2 are named, respectively, the relationship's *source* and *destination*.

Unlabelled arrows represent *hyponomies* (namely relationship *is-a*) between concepts. The relationship *is-a* relationship is used to specialize concepts in the ontology. For instance, vessels with stable volume are a particular type of vessels for fluids. Then the corresponding class Vessel with stable volume is a specialization, i.e., a *subclass,* of the class Vessel for Fluids. Similarly, the class Pressure vessel is a subclass of Vessel with stable volume. Through the relationship *is-a we* define taxonomies of concepts, which lead to hierarchical classifications.

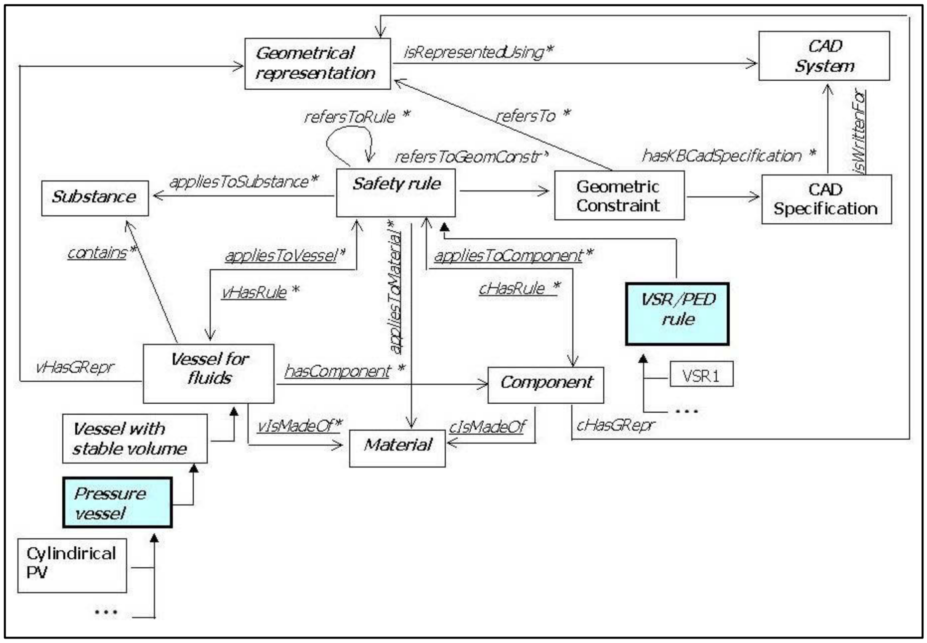


Fig 1. The pressure vessels and equipments ontology schema.

For instance, in Figure 2, the taxonomy of the vessels components is reported. Component is the root abstract concept of the taxonomy, and Member, Junction, Flange, etc. are specializations of Component.

Properties inheritance holds between classes related by the *is-a* relationship, i.e., a sub-class inherits all the properties defined in the more general class. Given for instance the taxonomy of Component depicted in Figure 2, each instance of type Cylindrical Shell inherits all the attributes and the relationships defined in the class Component, and the properties defined in the class Shell. The inherited properties are automatically defined for all the instances of Cylindrical Shell. Moreover, in Cylindrical Shell other properties are defined (e.g., the length of the shell).

Labeled arrows represent other relationships than *is-a*. These relationships are explicitly represented in the ontology by class attributes defined with an object type: i.e., the range of these attributes is given by the instances of classes defined in the ontology. For example, the relationship *contains* is defined between Vessel for fluids and Substance. In particular, since Substance is defined as an abstract class, the substance contained in the vessel must be one among those represented by the (non-abstract) subclasses Liquid and Liquefied gas. The relationship *contains* has been modeled explicitly, because, in general, the characteristics of the substance that will be contained in the vessel influence the design.

Labeled starred relationships are multivalued, i.e., one instance in the source class can be related to more than one instance in the destination class. For example, the relationship *hasComponent* that holds between Vessel for Fluids and Component is defined as multivalued because a vessel for fluids is composed by (potentially) more than one component, e.g., shell, ends, openings, etc.

Labeled relationships with underlined labels are mandatory, i.e., for each instance of the source class at least one instance in the destination class must be defined. For example, a Vessel for fluids is made of at least one Component. Differently, the minimum cardinality of the relationship v*HasGRepr* defined between Vessel for fluids and

Geometrical representation has been set to zero, i.e. a Vessel for fluids can be represented in the ontology without the corresponding geometrical representation.

Bi-directional labeled arrows represent a pair of relationships, one inverse of each other. Both relationships are represented explicitly in the ontology. For instance, the relationship *appliesToVessel* is defined from Safety rule to Vessel for fluids, i.e. a safety rule applies to a (set of) vessel for fluids. Its inverse is the relationship *vHasRule*, that holds from Vessel for Fluids and Safety rule. Note that both the relationships are multivalued.

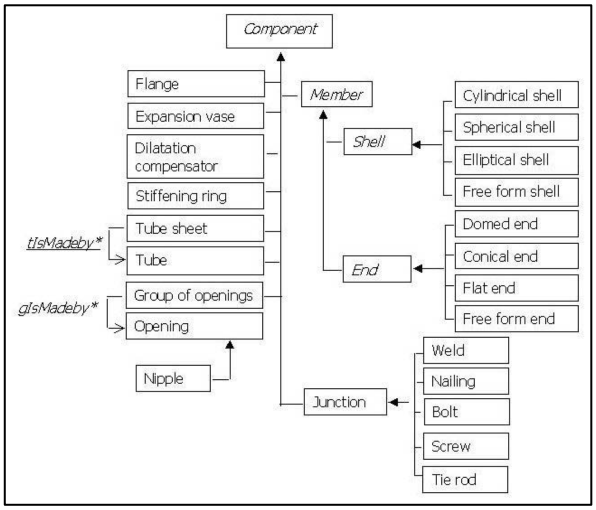


Fig. 2. Component's taxonomy.

2.1 Safety Rules

Safety rule is the core concept of the ontology depicted in Figure 1. A safety rule applies to one or more component (*appliesToComponent*) of a given vessel for fluids (*appliesToVessel*) that has been designed to contain a specific substance. The component is made of a specific material, and is one of the materials employed to build the vessel. The same rule can apply to a group of substances (*appliesToSubstance*) that can be contained in the vessel, and to a group of materials employable for the construction of vessels and vessel components (*appliesToMaterial*). The substance contained in the vessel and the materials employed for the component (and for the vessel) are included in the lists of substances and materials the rule applies to. The relationships c*hasRule* and v*hasRule* are the inverse relationships of *appliesToComponent* and *appliesToVessel*, respectively. These relationships are used to retrieve directly the safety rules that apply to a given vessel and to its components.

Each rule can include one or more Geometric constraints, which refer to a set of geometric features in the Geometric representation of the Component. Furthermore, each Geometric constraint can be specified according to the syntax of the knowledge-based CAD system employed (*hasKBCADSpecification*).

The safety rules considered in this framework are the VSR/PED rules [7]. For pressure vessels design and verification, many codes are available. In past decades, the main industrialized countries developed their own codes, such as BS5500 in UK, ASME VIII-div.1 in USA and AD-MERKBLATT in Germany. In Italy a set of rules for pressure vessels stability verification, namely VSR code, has been developed by constructors and public bodies and enforced by the law in the early seventies. For twenty years, ISPESL [6] has been in charge to manage and update this code. In 1997, the European Commission issued the Directive 97/23/CE/ (PED 1997) in order to allow the free trade of pressure equipments across the Union. The Directive does not enforce any national code, but defines only general criteria, named Essential Safety Requirements (ERS), which have to be verified to approve pressure equipments.

VSR code has been harmonized with PED directive, and nowadays it is widely used in Italy for pressure equipments design and approval. VSR rules define minimal thickness of pressure equipments (e.g., cylindrical or spherical shells of domed or conical heads and covers, of flat ends and plates) and state safety conditions on all vessel details, such as stiffening rings, openings, flanges, jackets, nozzles, valves and tube-sheets. In VSR code, conditions are expressed as functions of: geometrical parameters (e.g., diameter, length, width, distance, angle, areas and volume); operational parameters (e.g., peak pressure, test pressure, design pressure, operation temperature); and material features (e.g., elasticity modulus, Poisson coefficient and corrosion allowance). Moreover, VSR safety rules follow all the pressure equipment lifecycle: they include rules for construction, for testing, for inspection along operation time, as well as for repair and modification. For example, the group of rules VSR.1.L.2 applies to flat plates and circular flat ends without openings made by unalloyed steel or weekly alloyed steel (austenic steel excluded). In particular, according to the rule VSR.1.L.2.1, the minimum thickness (s_0) of these components is $s_0 = C \cdot D \sqrt{\frac{p}{f}}$, where *p* is the internal pressure of the vessel, *f* is the maximum effort of the material employed for the components, and C is a form coefficient. Moreover, specific geometric constraints among the geometric parameters of the components must be verified, according to the different cases of junctions among the ends and the planes of the vessel. In Figure 3, the first case handled by the rule VSR.1.L.2.1 is reported. The two formulas in the figure express constraints among geometrical parameters of the components involved.

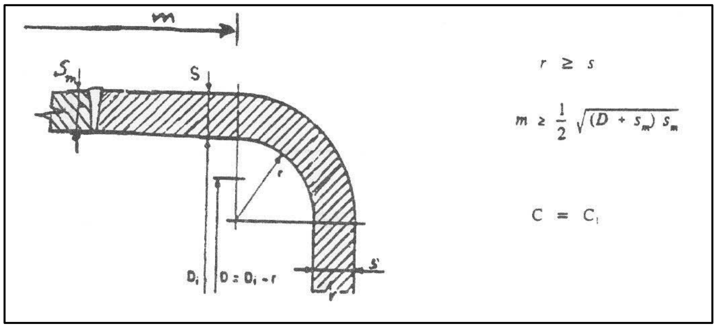


Fig. 3. Example of rule: VSR.1.L.2., case 1.

In the ontology, an instance of the class VSR.1.L.2 is created to represent the general rule VSR.1.L.2.1. Moreover, another instance of the same class represents the specific case depicted in Figure 3. These instances are related to the components, vessels, materials, and substances these rules refer to by means of relationships, whose values are bounded according to specific class axioms and restrictions (cf. Section 2.3). Moreover, the instance representing the rule of Figure 3 is related to the set of instances representing the geometrical constraints reported in the figure. These constraints are translated in a set of specifications interpretable by the knowledge-based module of the considered CAD system, and are used to apply and verify the rule. For each constraint, and for each KB-CAD specification, we created instances of class Geometrical constraint and CAD Specification, respectively.

2.3 Ontology Axioms and Restrictions

In the pressure vessel and equipment ontology, we defined also a set of class axioms to formalize restrictions on the relationships and conditions that consistent ontology instances should satisfy in order to describe correctly the application domain. The axioms are description logic formulas, specified by using the OWL-DL language. Unfortunately, the current specification of OWL-DL is very limited, and only very simple constraints can be specified using the syntax provided. In particular, constraints that require the specification of *path expressions* are not supported. Nonetheless, the set of constraints that one can specify allows supporting the user during both the design and the inspection phases. The most meaningful axioms are expressed as restrictions on the participation of the class instances to the relationships.

For instance, a crucial constraint for the tool requires the restriction of the application of VSR rules to pressure vessels, and not to the whole domain of vessel for fluids. The relationship *appliesToVessel*, originally defined in the class Safety rule with Vessel for fluids as codomain, must be restricted in the class VSR/PED rule, which inherits this relationship and its definition, to have only Pressure vessel instances as values. This constraint has been specified in OWL-DL using the following pair of (necessary) conditions:

∃ *appliesToVessel* Pressure vessel
∀ *appliesToVessel* Pressure vessel

The first restriction requires that each VSR/PED rule refers to at least one Pressure vessel (i.e., at least one value exists for the relationship *appliesToVessel*); the second restriction requires that, whenever the relationship *appliesToVessel* has a value in a VSR/PED rule instance, an instance of Pressure vessel is the relationship target. Since for each instance of VSR/PED rule both restrictions must be satisfied, the domain of the relationship *appliesToVessel* is bounded to the instances of the class Pressure vessel. This type of specification, that requires both an existence and a universal constraint be specified on the same relationship, is also referred to as *Closure Axiom*. Similarly, a closure axiom has been defined for the relationship v*HasRule,* the inverse of *appliesToVessel*, defined in Vessel for fluids with values of type Safety rule. v*HasRule* is inherited in the class Pressure vessel, and its codomain must be restricted to VSR/PED rule instances. Specifically, for each instance of Pressure Vessel, the following pair of constraints holds:

∃ *vHasRule* VSR/PED rule
∀ *vHasRule* VSR/PED rule

Both *appliesToVessel* and v*HasRule* are mandatory and multivalued relationships, i.e., given a Vessel for fluids, at least one Safety rule exists that applies to it; moreover, each rule refers to one or more vessels. Both conditions can be expressed as constraints on the cardinality of the relationships (namely, *cardinality restrictions*), i.e., by specifying that at least one value must be defined for each relationship. Specifically, in the class Vessel for fluids the following restriction has been defined:

≥ *vHasRule 1*

Moreover, the following restriction has been defined in the class Safety rule:

≥ *appliesToVessel 1*

Note that, in classes Pressure vessel and VSR/PED rule, the minimum cardinality constraints for relationships *vHasRule* and *appliesToVessel* are already satisfied by the specification of the existence restrictions specified by the previous closure axioms, but these axioms do not apply to the other Vessel for fluids and Safety rule subclasses. Then, the specification of the above cardinality constraints is required in the superclasses.

Other closure axioms have been defined to restrict the application of specific classes of VSR rules to specific materials and components, as discussed above. For instance, for rules that belong to the group VSR 1, that apply to pressure vessels and components made by unalloyed steel and weekly alloyed steel (excluding the austenic steel) the following closure axioms are defined in the class VSR 1 (and inherited by all its subclasses):

∃ *appliesToMaterial* Unalloyed steel ∪ Weekly alloyed steel
¬ *∃ appliesToMaterial* Austenic steel

∀ *appliesToMaterial* Unalloyed steel ∪ Weekly alloyed steel
¬ ∀ *appliesToMaterial* Austenic steel

where Unalloyed steel, Weekly alloyed steel and Austenic steel are subclasses of the class Steel. Similar closure axioms are defined to restrict the application of rules VSR 2, VSR 3, VSR 4, and VSR 5 to the correct materials.

Other restrictions are specified to restrict the codomain of the relationship *appliesToComponent*, and then the application of a set of rule to the correct component type. For instance, the VSR 1.L rules are defined for the verification of flat plates and flat ends. Therefore, in the class VSR 1.L the following axioms are specified:

∃ *appliesToComponent* Flat plate ∪ Flat End
∀ *appliesToComponent* Flat plate ∪ Flat End

where Flat plate and Flat End are subclasses of Component. In particular, as we discuss above, the rule VSR.1.L.2 applies to flat plates and flat circular ends. Then the following constraints apply to the instances of class VSR.1.L.2:

∃ *appliesToComponent* Flat Circular End
∀ *appliesToComponent* Flat Circular End

where Flat circular end is a subclass of Flat end.

3. A PROTOTYPE TOOL FOR PRESSURE EQUIPMENT DESIGN AND INSPECTION

The general architecture of the knowledge-based tool for supporting pressure equipment design and inspection, is shown in Figure 4:

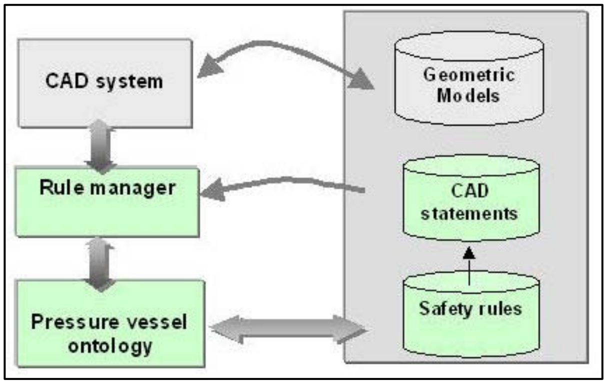


Fig. 4. Architecture for a KB-tool for pressure vessels equipments design and inspection.

In this general framework, the Rule Manager accesses to rule and vessel models through the ontology and the CAD system. In particular, by querying the ontology it retrieves the normative rules and the corresponding CAD statements.

For instance, the group of rules VSR.1.L.2 we mentioned in the previous section is retrieved whenever the user inserts in the ontology an instance representing a flat circular end or a flat plate end, which are the type of components this rules apply to. The rules are retrieved through a query of the form (see figure 5):

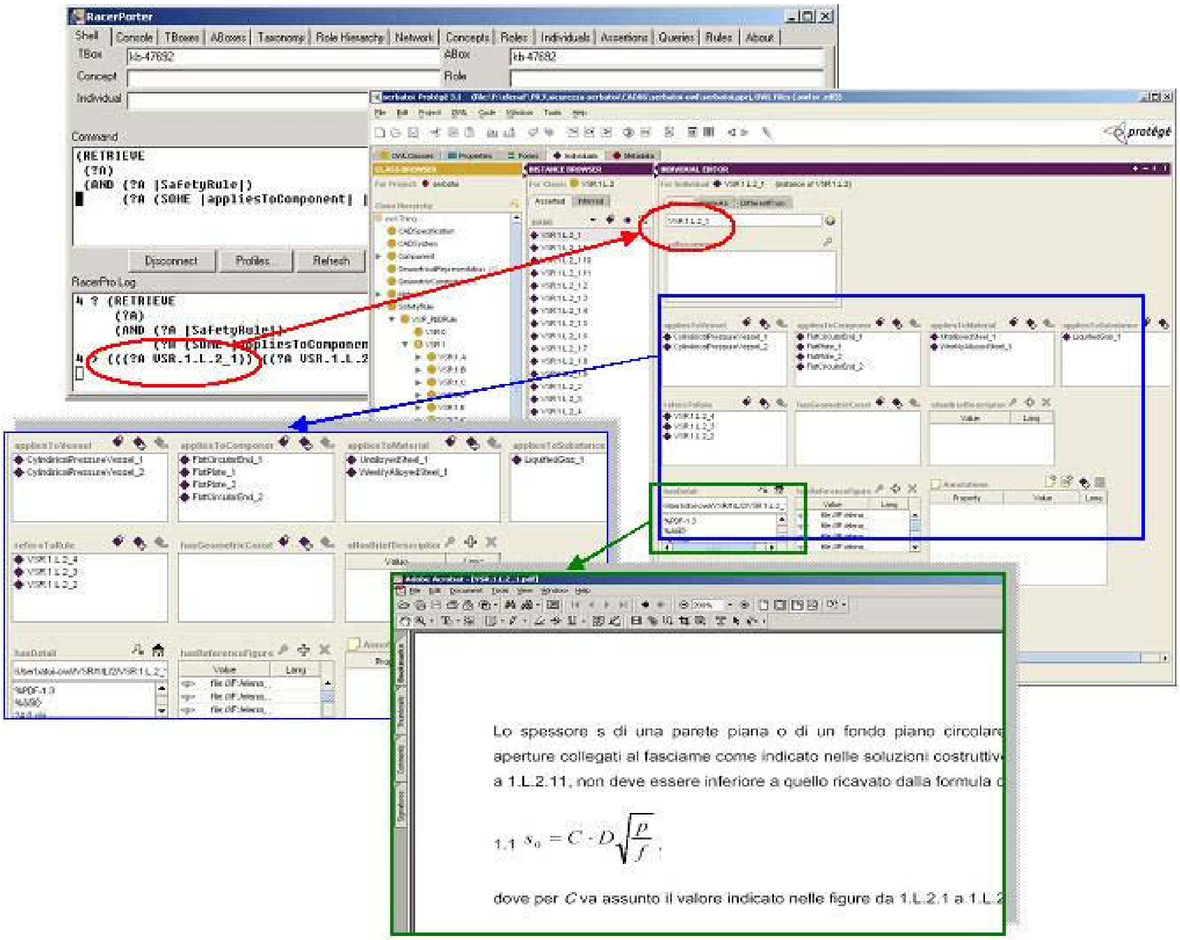
```
(retrieve (?a) (and (?a |SafetyRule|) (?a (some |appliesToComponent| |FlatCircularEnd|)))).
```

The syntax used in this example is nRQL-like. nRQL is the query language used by RacerPro© from Racer Systems, which is the description logic *reasoner* we apply for checking the ontologyconsistence. The instances retrieved by this query are those representing the safety rules (see Figure 5) of interest.

To verify the compliance of pressure vessels CAD models with the VSR rules, it is necessary to convert the different digital representations as supplied by manufacturers (i.e., models made with different CAD systems), into a coherent representation schema. This representation schema has to be compliant in terms of parameters and constituting elements with the vessel component specification as described in the ontology.. It also considers a feature-based description of the elements, as those that can be obtained by applying automatic recognition systems, or through interactive procedures as those commonly provided by commercial CAD systems.

To check the feasibility of the approach we propose, a prototype system has been developed relying on CATIA_V5® from Dassault-Systèmes. The prototype uses the CATIA V5®'s customization tools for accessing geometric data, and the "Knowledgeware" module for defining and verifying design rules. In CATIA_V5®, rules management is deeply integrated with the parametric CAD modeler. This capability has been exploited to develop the software prototype. However, this is not a strong limit to spread experiment results. In fact, rules management integration is present in other high-end CAD products; then prototype porting into these systems is feasible.

The developed user interface is very easy and close to the common way of working both of designers and inspectors and the terminology used is the same employed by the VSR norms. Pressure vessel designers are used to fill in detailed forms to obtain the required VSR compliance certificate, and the developed user interface follows the same approach of these forms. Therefore, designers do not need to learn a new specific and complex tool. They have just to fill in the electronic forms, then the application, by using a very little subset of specific CAD commands, generates automatically the complete assembly (see figure 6 (a)).



TBox kb-47692
ABox kb-47692
Concept
Role
Individual

Command

```
(RETRIEVE
 (?A)
 (AND (?A |SafetyRule|)
      (?A (SOME |appliesToComponent| |
```

RacerPro Log

```
4 ? (RETRIEVE
     (?A)
     (AND (?A |SafetyRule|)
          (?A (SOME |appliesToComponen
4 > (((?A VSR.1.L.2_1)) ((?A VSR.1.L.2
```

appliesToVessel: CylindricalPressureVessel_1, CylindricalPressureVessel_2

appliesToComponent: FlatCircularEnd_1, FlatPlate_1, FlatPlate_2, FlatCircularEnd_2

appliesToMaterial: UnalloyedSteel_1, WeaklyAlloyedSteel_1

appliesToSubstance: LiquefiedGas_1

refersToRule: VSR.1.L.2_4, VSR.1.L.2_3, VSR.1.L.2_2

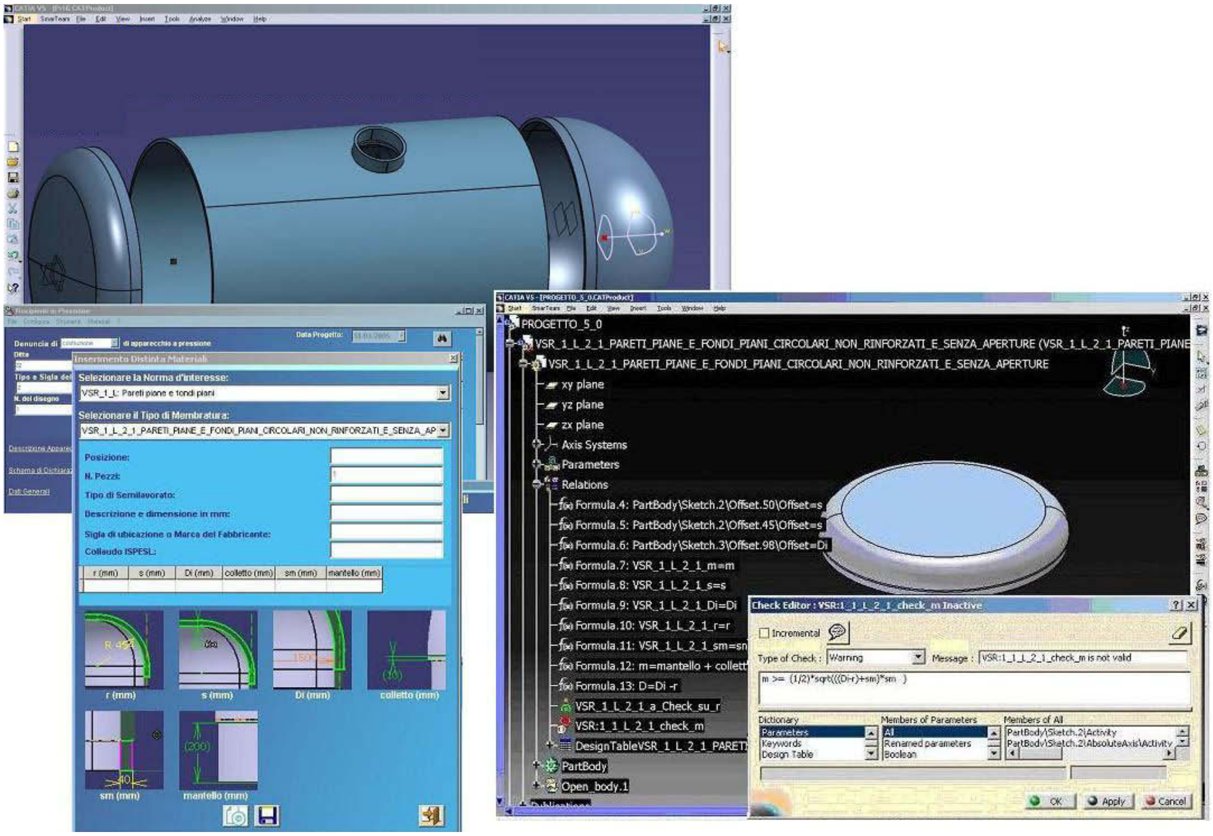
Lo spessore s di una parete piana o di un fondo piano circolar
aperture collegati al fasciame come indicato nelle soluzioni costruttiv
a 1.L.2.11, non deve essere inferiore a quello ricavato dalla formula d

$$1.1 \quad s_0 = C \cdot D\sqrt{\frac{p}{f}}\,;$$

dove per *C* va assunto il valore indicato nelle figure da 1.L.2.1 a 1.L.2

Fig. 5. Instances for Safety Rule VSR.1.L.2.

At the design stage, the user specifies the general type of apparatus he/she is designing, with its dimensions and operating conditions (e.g., pressure, temperature, materials, type of fluids, and main features), by selecting it from an electronic catalogue, which is compliant with the specified ontology. Then he/she adds the various elements, e.g., ends and shells, and defines the related parameters according to the VSR notation. Details, such as branches openings or nips, may be added on the main items (shell or ends). Also detail parameters are defined through a VSR-like interface, then details are positioned using a simple CATIA V5® command. Following this easy path, the designer creates a true solid model of the part, which is the essential input for the containment verification as well as for the stress calculations. From the inspector point of view, currently we adopted the procedure of letting the user to rebuild a synthetic digital representation of the equipment, in a manual but assisted way, using just the data supplied by manufacturer in the certification request form. A synthetic equipment model is created in the CAD system, to provide a simplified graphical representation; then VSR rules are automatically checked. All the rules applicable to the equipment under consideration are visualized by the graphical user interface with a traffic light icon associated, as normal practice in CATIA V5®: a green light means compliance, while a red one means discrepancy. Figure 6(b) shows an example of automatic VSR checking on a vessel end. In this case, the red light indicates that a deviation occurred; in particular the thickness of this specific end does not comply with the specified formula.



Denuncia di costruzione di apparecchio a pressione

Data Progetto:

Ditta

Tipo e Sigla del

N. del disegno

Inserimento Distinta Materiali

Selezionare la Norma d'interesse: VSR_1_L: Pareti piane e fondi piani

Selezionare il Tipo di Membratura: VSR_1_L_2_1_PARETI_PIANE_E_FONDI_PIANI_CIRCOLARI_NON_RINFORZATI_E_SENZA_AP

Posizione:

N. Pezzi: 1

Tipo di Semilavorato:

Descrizione e dimensione in mm:

Sigla di ubicazione o Marca del Fabbricante:

Collaudo ISPESL:

r (mm)	s (mm)	Di (mm)	colletto (mm)	sm (mm)	mantello (mm)

CATIA V5 - [PROGETTO_5_0.CATProduct]

- PROGETTO_5_0
  - VSR_1_L_2_1_PARETI_PIANE_E_FONDI_PIANI_CIRCOLARI_NON_RINFORZATI_E_SENZA_APERTURE (VSR_1_L_2_1_PARETI_PIANE
    - VSR_1_L_2_1_PARETI_PIANE_E_FONDI_PIANI_CIRCOLARI_NON_RINFORZATI_E_SENZA_APERTURE
      - xy plane
      - yz plane
      - zx plane
      - Axis Systems
      - Parameters
      - Relations
        - Formula.4: PartBody\Sketch.2\Offset.50\Offset=s
        - Formula.5: PartBody\Sketch.2\Offset.45\Offset=s
        - Formula.6: PartBody\Sketch.3\Offset.98\Offset=Di
        - Formula.7: VSR_1_L_2_1_m=m
        - Formula.8: VSR_1_L_2_1_s=s
        - Formula.9: VSR_1_L_2_1_Di=Di
        - Formula.10: VSR_1_L_2_1_r=r
        - Formula.11: VSR_1_L_2_1_sm=sn
        - Formula.12: m=mantello + collett
        - Formula.13: D=Di -r
        - VSR_1_L_2_1_a_Check_su_r
        - VSR:1_1_L_2_1_check_m
        - DesignTableVSR_1_L_2_1_PARET
      - PartBody
      - Open_body.1

Check Editor : VSR:1_1_L_2_1_check_m Inactive

☐ Incremental

Type of Check : Warning

Message : VSR:1_1_L_2_1_check_m is not valid

```
m >= (1/2)*sqrt(((Di-r)+sm)*sm )
```

Dictionary	Members of Parameters	Members of All
Parameters	All	PartBody\Sketch.2\Activity
Keywords	Renamed parameters	PartBody\Sketch.2\AbsoluteAxis\Activity
Design Table	Boolean	

(a) (b)

Fig. 6. The software prototype: (a) Construction of a pressure vessel according VSR rules (b) VSR rule verification.

4. CONCLUSIONS

Some recent computer science advances offer potential chances for increasing plant safety. Among these, the automated check of safety rules embedded into part models designed through CAD systems is interesting. For such a goal, to have sound codes of safety rules is essential. Further advantages may be expected from using KB-CAD systems to assist the Competent Authorities during part design approval: by using an automated rule checker, they could make a first coarse evaluation of safety compliance of plant equipments. This first step would constitute a good base for a fast approval process.

The knowledge-based tool presented in this paper is able to support both the application of the considered safety normative in the first stages of pressure vessels design process, and its verification *a posteriori*. The current normative pressure vessels must comply with has been formalized in a specific domain ontology. The present version of the prototype supports a domain restricted to this normative, as applied in Italy. However the ontological technology allows extending the knowledge base of the tool easily to a wider set of rules or equipments. For instance, the complete domain of vessel for fluids can be easily managed. The extension of the ontology is straightforward: first, the classes representing the sets of rules and their application domain have to be defined as subclasses of the classes already defined in the ontology, specifically those that represent the overall concepts; then, instances for these classes must be created, representing the specific rules and the related pressure vessels and equipments.

As for the domain knowledge, another advantage of the described methodology is that other knowledge base CAD systems than CATIA V5® can be supported, simply by extending the ontology with the opportune classes and instances and changing the CAD statements according to the system under consideration.

In contrast, the main limitations of the proposed approach are inherent to the need of using the specific features and parameters (i.e., those included in the ontology specification) for describing the vessel model, in order to automatically verify the involved norms; this could not be guaranteed because of the designers way of proceeding and of the adopted CAD capabilities. Anyhow, being the features and parameters in the ontology meaningful from the functional point of view, thus closer to the view the designer has of the vessels, the possible mismatches should be limited. Also the use of automatic or interactive feature recognition systems, which has not been fully tested to verify the effectiveness, would anyway require some additional effort to put the extracted parameters in relation with those considered in the ontology.

In the current prototype, the user interface of the ontology is realized through the Protégé Graphical User Interface. The extension of the prototype is currently in progress in order to make the interaction with the ontology completely transparent to the user by improving the integration with the knowledge base CAD System.

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