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A strategy for Cast Part Design Process Optimisation: Customer Inquiry Specification Phase

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Abstract
In the increasing competition from Newly Industrialised Countries in Asia like China, the Finnish foundries are faced to change their service concept to more customer service oriented and integrated to the design process of casted parts to avoid to compete in low cost cast segment. The paper presents a framework and concept for foundry industry to create enabling technology to create a service concept for design services, where a foundry can create a full service for casted parts design and production. The key element is a new customer interface, where the customer communicates with the foundry by a process, which is created by the foundry or foundry near engineering service company. The communication is standardised with Entity-Relationship modelling, describing a SQL-database, XML-based inquiry data document and generic URL-linked CAD-files based on surface modelling.

1 Introduction

1.1 Background
Current practice in cast part acquisition is based on a process, where the foundry´s customer sends an inquiry, where the part is comprehensively detailed in geometry, material and surface treatments specification. In this practice, the foundry supply chain’s possibility to support the design process with cast part design know-how is substantially reduced. The foundry’s potential to provide added value for the customer by competence is diminished, and the business relation is reduced to a manufacturing capacity sales competition instead of close co-operation with the customer including genuine value add by cast supply competence. [1].

In the past years, Newly Industrialised Countries (NIC) and emerging economies like India and China are pushing their production capacity to the global market. While the cost of materials is increasing and as low transport costs can be obtained anywhere on the globe with low cost variation, the labor costs of mentioned type countries give large competitive advantage for them. Like any other industries, the foundry industry in Europe is threatened by the labor cost differences, even if these highly developed countries have more skilled resources, machines and IT-technology, historically developed foundry industry and infrastructure. However, also the increasing mean age of foundry staff and large number of expected retierings in coming years present new difficulties. [1]

1.2. Objectives

The objective of this paper is to present a cast part design and modeling strategy, which is founded on the principle, that customer needs not a physical cast part as such, but only a set of mechanical functional surfaces, ability to transmit forces and elasticity between them, and certain qualities of dimensions, tolerances, aesthetics and treatments on these surfaces. [2]
Thus, there is a need to re-define the traditional customer inquiry model to obtain a design process, where the design features of cast parts, which are independent from customer requirements, can be defined later in the design process, and thus is not necessary by the customer, but by foundry. This approach enables the part to be optimized by requirements of tolerances, material, weight, manufacturing methodology and price. Also, the re-definition of the customer inquiry model enables to re-organise customer foundry design process: With a neutral format inquiry specification model the foundry can concentrate on further development of the cast part with it's own native cast design analysis software.

1.3. Approach

The design process on single part level is based on a principle, that part design begins from the specification of functional surfaces, the function carriers. The functionally specified boundaries contact with other parts. In the specifying geometry, the size, distances and tolerances are determined as also the surface roughnesses and surface treatments. Thus, the customer of a part manufacturer, i.e. foundry, should not specify more than what is required for the functional surfaces. More over, the functional surfaces must be able to transmit the loads between the load carrying surfaces. Therefore, with modern 3D CSG (Constructive Solid Geometry) modelers, the design process can be organized as in fig. 1. The customer specifies only the three first steps of fig.1. The customer's needs for functional surfaces are determined and fixed, while the load carrying features are not. The dimensioning for the load carrying features can be optimized later. Thus, the specification is possible to be created with any CAD-system capable to output neutral file format.

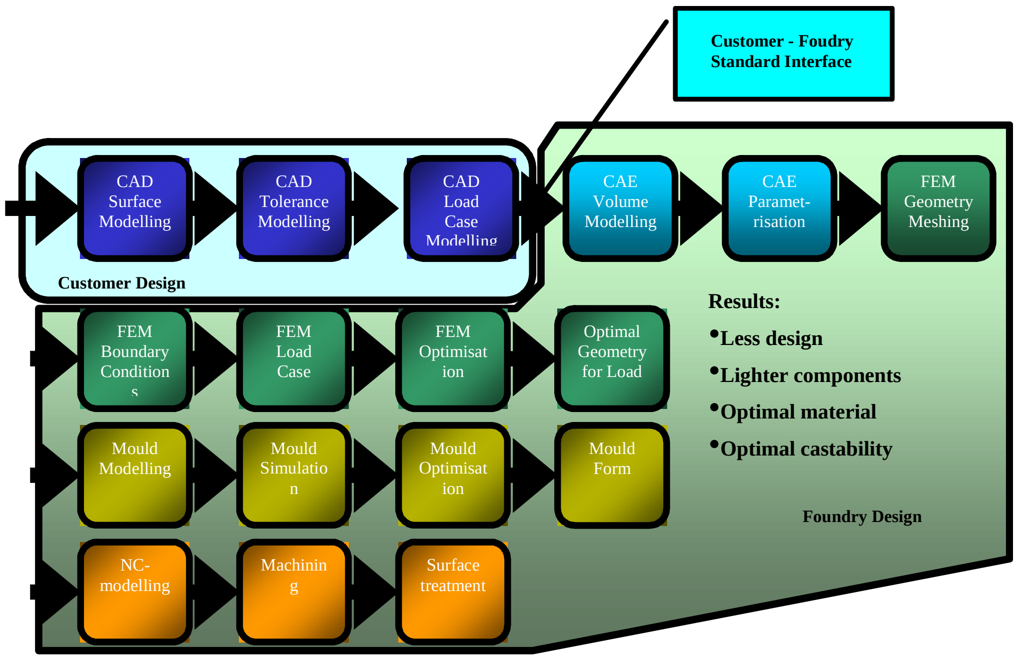

Figure 1. Design process of cast parts

The part manufacturer in the foundry can then continue from the customer - foundry standard interface with their own native file format and design the part topology and dimensions with respect to optimization criteria concerning weight, stiffness, strength, material, and in-house manufacturing resources. The full capacity of the foundry's design competence can be utilized, and the foundry can be integrated to the customers manufacturing process as an independent partner with design responsibility.

2 State of the art

To maintain their position at the front edge of the foundry branch, European companies have obtained many tools to serve their customers with high quality castings. The key issue, which foundries have to face is, that ***a cast is not a product***. To maintain the competitive edge, foundries must integrate their processes with the customer product development process, rather than letting the customer to do the design and preliminary production planning for the product.

The foundries must therefore change their focus from their physical cast products to service concepts, including design support from the beginning of the life cycle to end of it. This paper focuses on the design phase of the cast. The objective is to concentrate on the design service interface from the beginning of the design to cast order specification. Coming papers will continue from this on. It is also evident, that the earlier the manufacturing specialists can consult the designer, the easier manufacturing process can still be reconsidered and thus the manufacturing cost, efficiency and other downstream decisions can be left for manufacturing specialists to reduce cost and supply time.

The research on computer support tools in industry has been based on many different kinds of approaches. This literary study was performed based on search from El Compendex Web database with recent CAD/CAM/CAE publications on cast CAE:

- Knowledge based expert systems for manufacturing have been presented by Er & Dias, where the casting alloy, geometric complexity, casting accuracy production quantity and comparative costs can be considered [3],
- Recognition of form features for casting is based either on interactive feature definition, where the features are defined from the geometric description of the designer, or the model is build by a set of specific form features selected from a pre-created library. The manufacturing aspects are created from a set of transformations compatible to the selected manufacturing process. In feature extraction method, the features are extracted from a solid model to create the model of the object. The model is then submitted to a process that attempts to recognise the shape features of the object relevant for the technical detailing. [4],[5]. A knowledge based system has been developed identifying nine types of die design components, boss, plate, wall hole, ribs and other features. [6]
- Database approaches for selection of materials and manufacturing process. [7]
- Assistance tools for cast planning, like feeder and runner systems designing, based on material databases, optimisation and genetic algorithms. Hu et al. have studied magnesium telecommunication parts' manufacturing with two types of gating system and analysed the swirling flow points and last filled areas and compared them to numerical analysis. [8],[9], [10]
- Studies and tools for separating objects from tools and definition planning tools for division planes of casts. Ahn et al. have studied the geometrical problem separating a cast to two opposite directions without the divided geometry to colliding each other or a other cast part. [11]

- CAD/CAE Systems for castings. Zhang and Xiong have developed a CAD system for designing the runner and gating systems according the characteristics of die-casting machine, the casting geometry and the properties of the alloy. The CAD system makes the basic dimensioning of the casting and die based on basic calculations. The CAE system is capable to analyse the thermal and flow field. [12]
- Determination of castability by geometry. An approach similar to Ahn et al., Bose et. al. have studied and developed a simple algorithm in the time of problem complexity of $n^2 \log n$. Also a more complicated algorithm has been developed. [13]
- CAD integrated RP and LOM-Method. Alain Bernard et al. have carried out a study based on tool manufacturing with rapid prototyping process. The created system allowed to study the usability of the tool and allowed to diminish the wall thickness to 4 mm. [14]
- Cast filling and solidification simulation tools. Zhang et al. have developed a finite element method for analysing with volume of fluid method for 3D-castings with thin-walled cavities. [15]
- Dimensionless approaches for cast life cycle analysis [16]
- Yue et. al. have developed a database approach for die casting expert system to be used together with Pro/Engineer CAD software and MAGMASOFT simulation software. [17]

3 Casted part design and order process

3.1 The ordering process of a casted part

Martin et. al. [18] have researched the design process of casted parts. According to them, the design of a casted part can be begun from the *functional surfaces model* (a), and from this, be stepwise refined to a product and production model. In the second phase this model is refined to a 3D solid *draft model* (b). For testing and optimisation purposes in the use phase, the part is optimised for use phase requirements in a *use behavioural model* (c). When the optimisation for use point of view are completed, the part is freezed as *designer final model* (d) to be then dispatched for manufacturing planning for further development.

As Martin et al states, many design offices supply only the designer final model and the planning department is integrated in the foundry division or exists as distinct entity. Nevertheless, in both cases the part is first designed to fullfill the use phase constraints and only after that to meet the manufacturing process and other life cycle requirements.
To increase the potential of concurrent engineering, this paper presents an approach where the brand owner of the product concentrates only on system level design based on Theory of Domains of Andreasen [19],[20]. For the use phase of the product, the requirements for the product are mainly concentrated on the customer requirements, which are concentrated as global or feature dealing requirements of the product (on *properties* of *process* and *organ* model as Andreasen it states). These requirements are best studied with generic function simulation models like Control Systems Models, Multi Body Simulation, and Finite Element Analysis, when the system is subject to dynamic or structural requirements and constrained and optimised by these requirements [21]. In this kind of design process, the brand owner can concentrate only on the design on system level and implementing organs. The part can be designed later only to full fill the *functional surfaces model*.

The cast industry in Europe is undergoing a development process, where the old foundry - machine chain is diversifying to include several players as proto shops, pattern makers, cast specialised engineering firms and so on. For Finnish foundries, to maintain it's position against international competition, the foundries must re-organise their structure so that the "virtual foundry" – coalition of companies can give full service for the European industry branches brand owners like automotive or power plant industry, what ever it serves – at the same time supplying full service and large volumes. This requires service, where the brand owner can concentrate it's own design on the system level only.

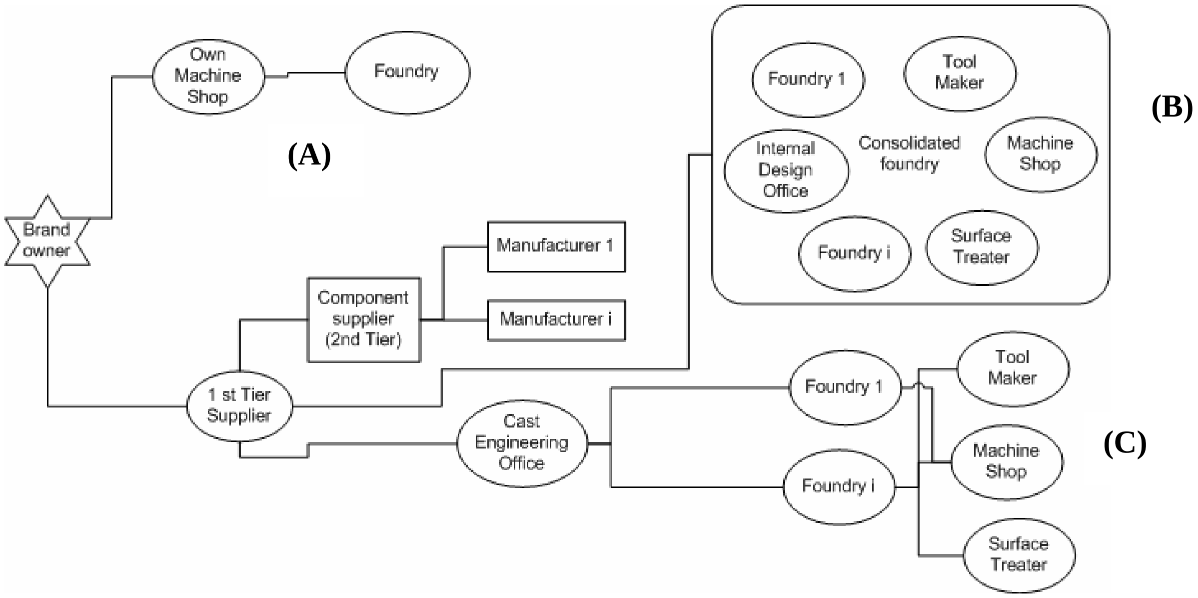

Figure 2. Cast industry supplier structure.

In fig. 2, two supply chains from brand owner to the product manufacturer are shown. In the *old operation model* **(A)**, there are few operators and the brand owner manufactures everything in it's own machine shop and buys casts from foundry. In the future, in the *consolidated model* **(B)**, a large consolidated foundry is offering many manufacturing lines, and full service for design and post cast services. These kind of foundries are competing with *networked supplier chains* **(C)** with cast specialised engineering offices, foundries, and pre- and post cast services. Parts are also bought from lower (2^{nd} level) company nets.

3.2 Overview of the approach

The approach presented in this paper describes a general framework for foundries to provide a service to exchange casted parts design and manufacturing inquiries related with the early design information. The information is related both to (**a**) *CAD geometry* (Surface model, Dimensioning and Tolerancing, (GD&T)), and (**b**) to *partially geometric requirements* like Load Cases, and (**c**) *non-geometric requirements*, like, Material properties, Manufacturability Use environment, Life-cycle and Economical requirements.

The basic surface CAD-file is presented in this paper as a generic VRLM-model (Virtual Reality Modelling Language). The model file contains the geometry related (**a**) data and also links to partially (**b**) or non-geometric related data (**c**). The data types (**b**) and (**c**) classes are the presented in this paper showing the possibility to model all the inquiry data belonging to these data-classes (**a-c**) with a SQL-database. This paper models as example the most relevant data types with an Entity-Relationship diagram (ER), and shows the links to/from CAD-file, which is VRLM-based linkage. The ER model is converted to a relation model and SQL-query language. With common tools, the model can be converted to XML-description, and read in for a data specification with Excel, Access or other database tools. The process of modeling the specification structure is shown in fig. 3.

Foundries may utilize this model for their processes and develop their own applications interface for their customers.

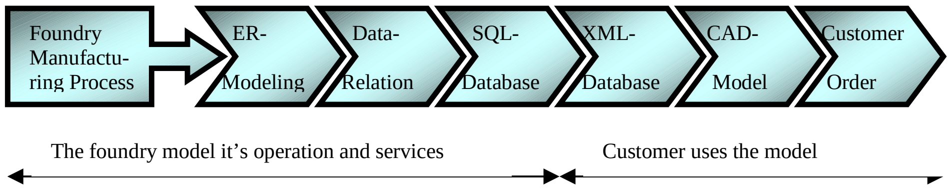

Figure 3. Foundry creates a design specification model for it's customers.

3.3. Specification model of a casted part

An example of the casted part main level design specification is shown in fig. 4. The main level contains the necessary ER-model information to create the databases for project management, and (a)-level data, which exists completely on the spreadsheet-like databases. All the data structure of (a)-level data are not shown in fig 4., but details of it are in fig. 5. The (b)-level data is partially connected to the geometry, and therefore it must contain a link to the design detail shown in the VRLM-file. Currently, these links are not yet implemented. However, links from VRLM-file back to database are possible. The final specification level for ER-created database is the (c)-level link to the VRLM-file.

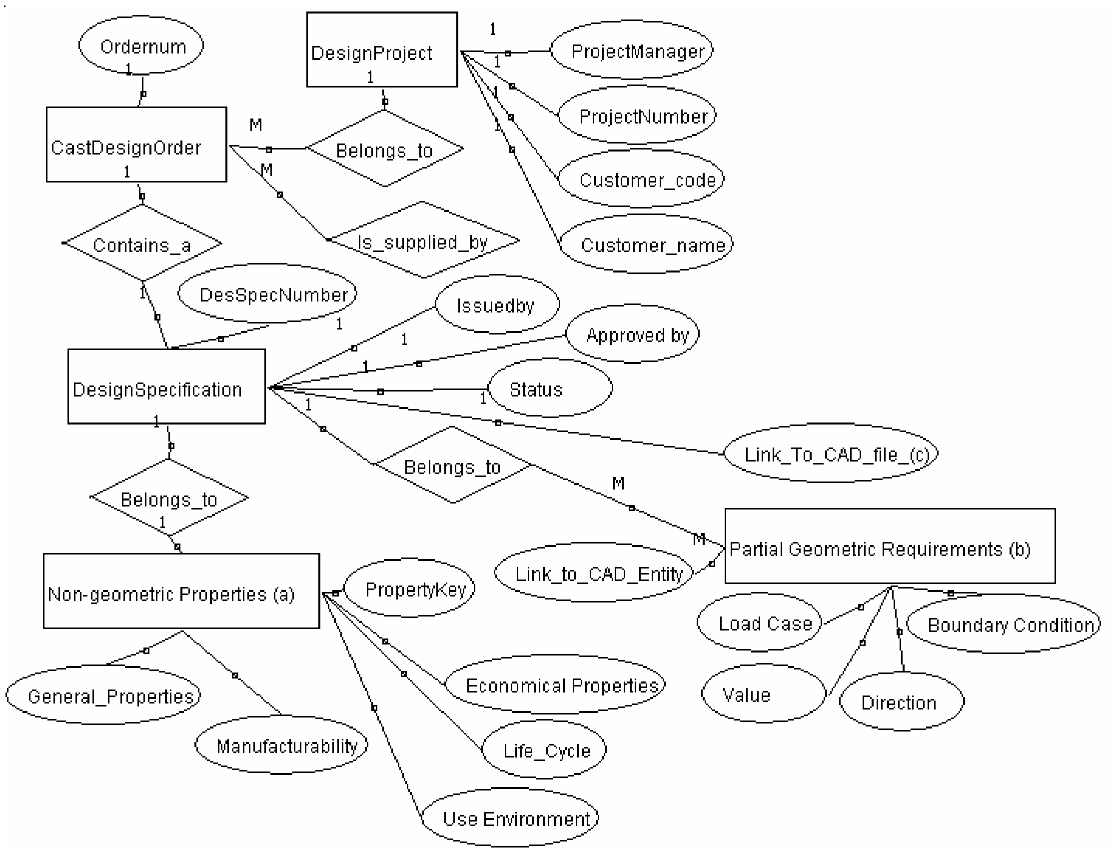

Figure 4. Customer cast design and manufacturing order main level ER-model.

In fig. 5, the detailed non-geometric specification is described as ER-model. This model contents all global data which is not attributed to a specific geometric detail. In this part of the database are stored most of the information, like all the material, environment and life-cycle information. Finally, the rest of the dimensional and tolerance information together with the geometric information are stored in (d)-level, that is, in the *VRLM-cad-file*.

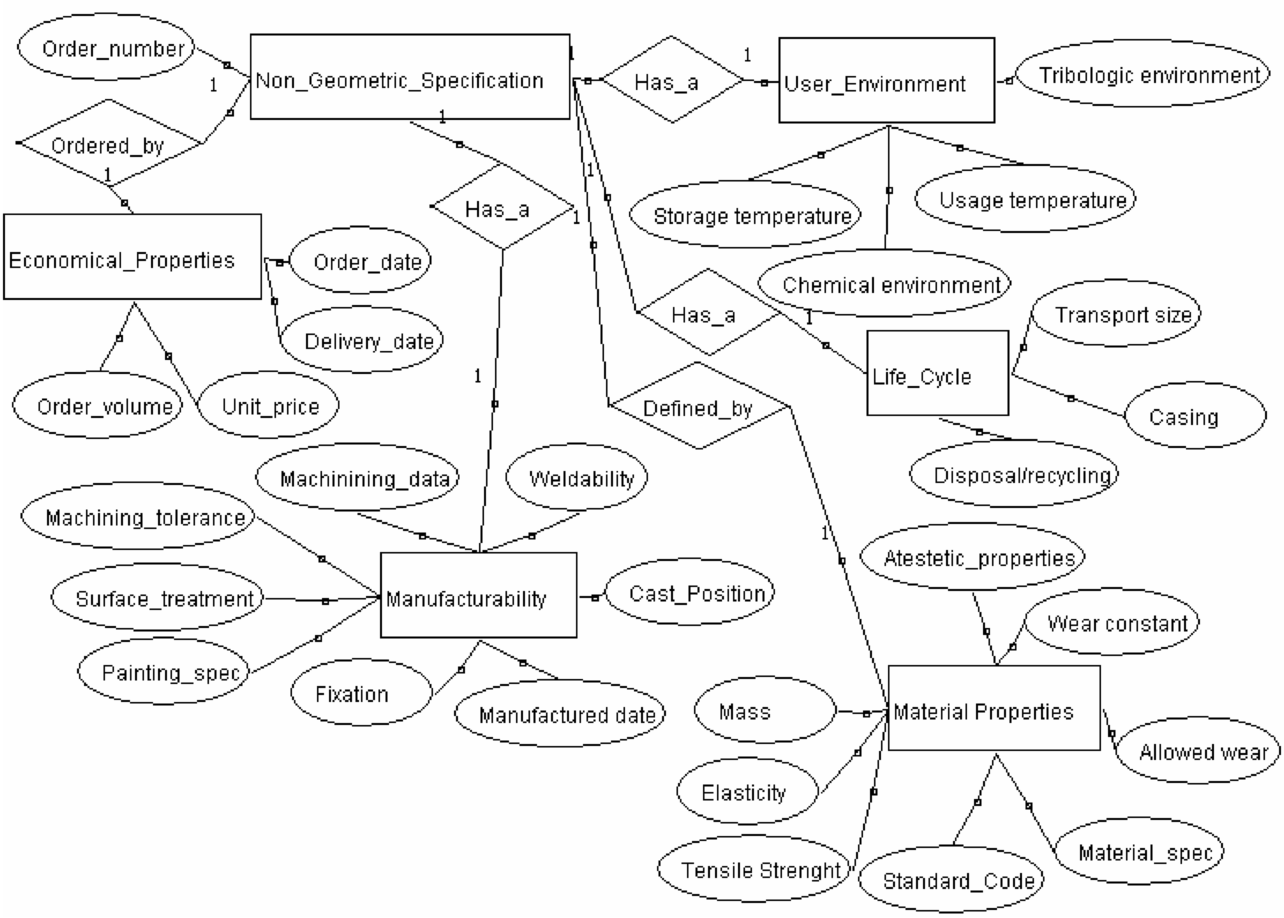

Figure 5. ER-submodel of the non-geometric properties.

3.4 Data relation model

From the ER-model, the database model with file structure are created automatically by Erkka-software, which is used for this case. Erkka is ER-tool developed with Java at University of Jyväskylä. [22]

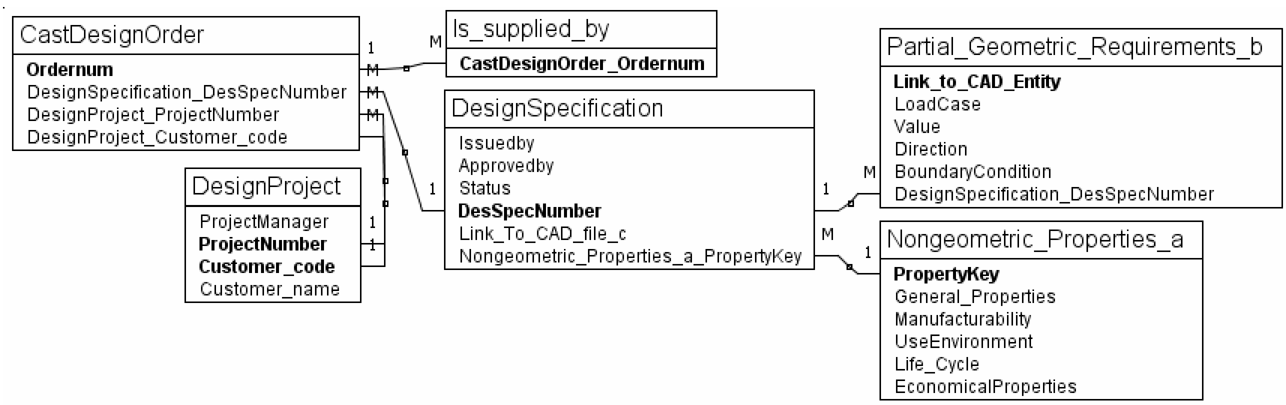

Figure 6. Main level data relation model, created from ER-model in fig. 4.

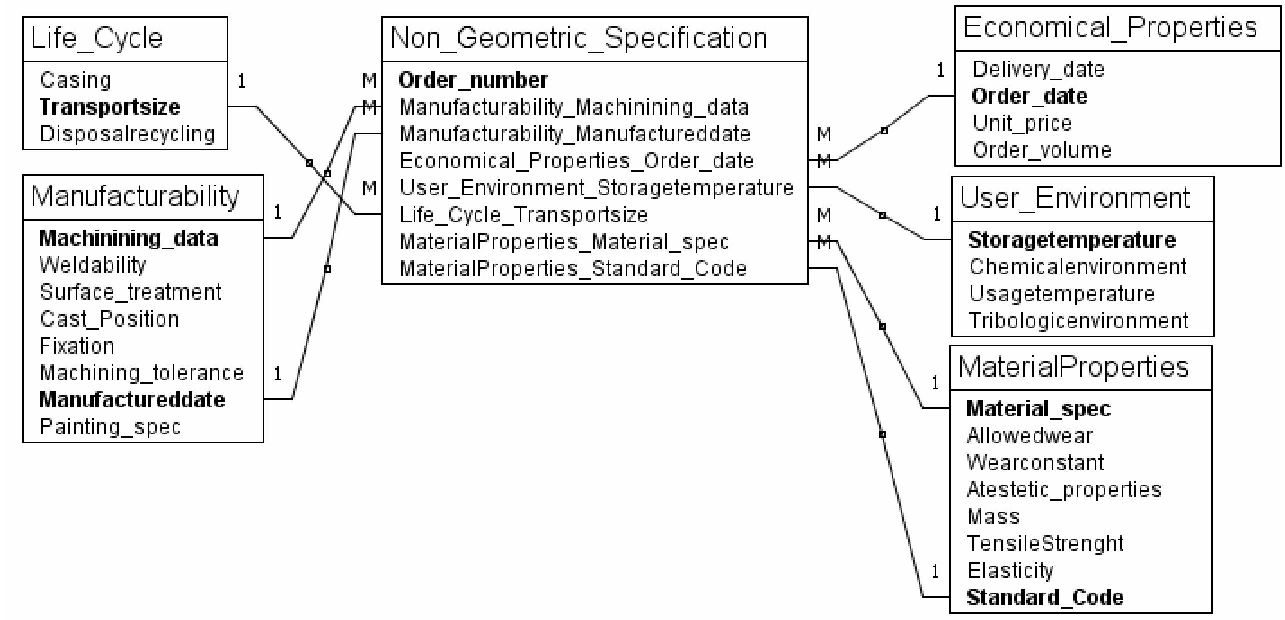

Figure 7. Non-geometric detail level data relation model, created from ER-model in fig. 5.

3.5 SQL-description

A standard feature of ER-modelling tools is the ability to create database scripts using SQL-language which is partially shown as an example in figure 8.

```
DROP TABLE Manufacturability
;
CREATE TABLE Manufacturability (
Machinining_data CHAR(250) NOT NULL,
Weldability CHAR(100) NOT NULL,
Surface_treatment CHAR(100) NOT NULL,
Cast_Position CHAR(10) NOT NULL,
Fixation CHAR(100) NOT NULL,
Machining_tolerance NUMERIC(5,2) NOT NULL,
Manufactureddate INTEGER NOT NULL,
Painting_spec INTEGER NOT NULL,
...
```

Figure 8. Partial representation SQL-script language.

3.6 XML-file representation

The database can be exchanged to be described as a XML-file read to database applications with several file transformation tools. This enables to read the database attribute descriptions to databases and used by customers as tools.

3.7 CAD-file representation possibilities

The file communication between customers can be based on many file types:

- Native model exchange doesn’t loose any information. The drawback is however, that the foundry must have modeling capacity with every CAD-software, which is expensive both in licencing and mantime costs.
- M2M (model2model) direct converters exists between many commercial software. The quality is varying but usually very good.

- 3DXML is a XML-based representation form for CAD-models, which is a open representation form of CAD Data published by Dassault Systeme's. It's contains however some trade secrets restricting it's use.
- VRLM is a acronym for Virtual Reality Modelling Language. It's 1.0 version is a subset of Inventor File format. It has possibility to contain links to URL:s. The current release of version is 2.0.
- X3D is a open standard for 3D content provision. It contains both functional parts, file format specifications and set of mappings.

The design process concept presented in this paper can be implemented with several of previous mentioned file representations. The most important requirement is, that the file type translator can transfer the CAD geometric properties and datalinks to non-geometric file specification of XML-type exists.

4 Results

The suggested design method presented in this paper was demonstrated using I-DEAS NX 11 Mod2 CAD software. The data relations were presented with Erkka ER-modelling software. An example of a piston initial design specification with some of the decided dimensions and surface treatments is shown in fig. 9a. The definition model in fig. 9a contains also the URL-links to the detailed requirements XML-document, which is modeled by Erkka or any other suitable ER-software and further specified Excel or Access or any other spreadsheet or database software capable to process XML-databases. The customer doesn't need to provide anything more that the initial design restrictions of system design of a product caused to a cast part A foundry related engineering office can then continue to design the detailed solid 3D model of a part, which is shown in fig. 9b.

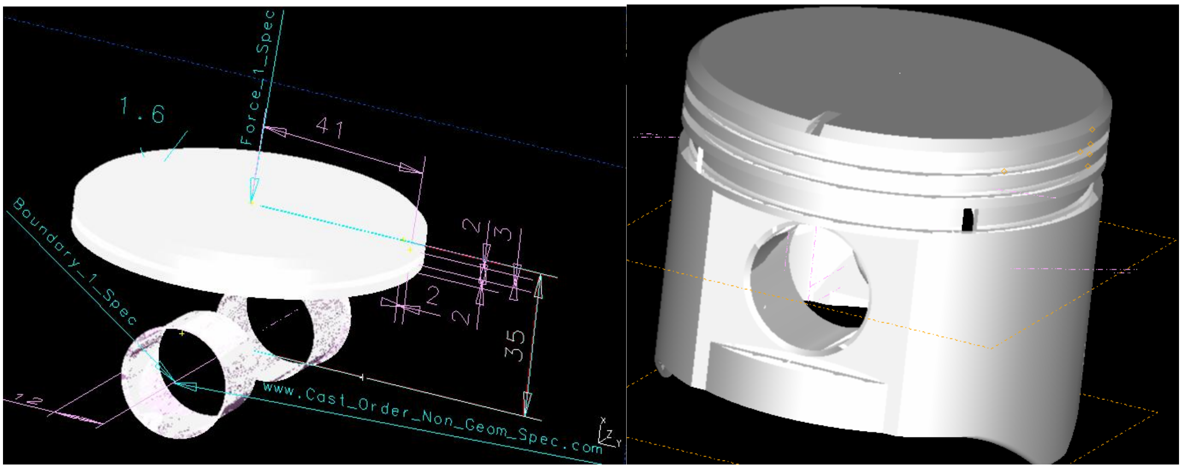

Figure 9. a (left) Example of surface model based design specification model with URL-links to XML-database. b (right) Final product model after foundry related detail design.

5 Summary and discussion

This paper has presented a framework for design process and necessary tools for a new horizontally integrated service concept for foundry industry. The generic concept has been demonstrated with simple internet-tools and is commercially creatable with small resources by foundry industry. Most of the process is straight forward implementable, while some minor details, like links from xml-database back to CAD-model, require some further development. The methodology can be used to enhance the very traditional foundry customer service concept.

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References

[1] Piha, O., Kansainvälisen hankintatoimen kehittäminen konepajassa, Masters Thesis, Helsinki University of Technology, (2003).

[2] Roy, U. and Bharadwaj, B., Design with part behaviours: behaviour model, representation and applications., *Computer-Aided Design*, Elsevier Science, 34 (2002), pp. 613-636.

[3] Er, A. and Dias, R. A rule-based expert system approach to process selection for cast components, *Knowledge-Based Systems*, Elsevier Science, vol. 13, (2000), p. 225-234.

[4] Stefano P. D., Automatic Extration of form features for casting, *Computer-Aided Design*, (1997) Elsevier Science, Vol 29, No 11., p 761-770.

[5] Kim, Y.S. and Wang, E., Recognition of machined features for cast then machined parts, *Computer-Aided Design*, (2002) Vol. 34, 71-87.

[6] Corbett, J. And Woodward, J. A. J., A CAD-integrated “knowledge based system” for the design of a die case somponents. Annals of CIRP, (1991) Vol 40. p 103-105.

[7] Giachetti, R.E., A decision support system for material and manufacturing process selection, *Journal of Intelligent Manufacturing*, (1998) No. 9, 265-276.

[8] Knight, B., Cowell., D and Preddy, K., An object-oriented support tool for the design of casting procedures, *Engineering Applications Artificial Intelligence*, vol. 8, No. 5 (1995), Elsevier Science, p561-567.

[9] Choi, J. C. et. al.., A Study on development of a Die Design System for Diecasting, *The International Journal for Advanced Manufacturing Technology*, Springer-Verlag, (2002), No 20, p1-8.

[10] Hu, B.H., et al., Design and Optimisation of runner and gating systems for the die casting of thin-walled magnesium telecommunication parts through numerical simulation., *Journal of Materials, Processing Technology*, (2000), Vol 105. p 128-133.

[11] Ahn, H.-K. Et. Al., Separating an object from it’s cast, *Computer-Aided Design*, Elsevier Science, (2002) Vol 34., 547-559.

[12] Zhang, W., Xiong, S. and Baicheng, L., Study on a CAD/CAE System of Die Casting., *Journal of Materials, Processing Technology*, (1997) Vol 63, p 707-711.

[13] Bose, P., Bremner., D. and van Kreveld, M., Determining the castability of Simple Polyhedra. *Algorithmica, Springer-Verlag*, (1997), No. 19, p 84-113.

[14] Bernard, A., et al., Integration of CAD and rapid manufacturing for sand casting optimisation, *Rapid Prototyping Journal*, Emerald, (2003) Vol 9, No. 5, p 327-333.

[15] Zhang, Y_F., Wing, K-L., Wang H-P. Cast Filling simulations of thin-walled cavities, *Computer methods in applied mechanics and engineering*. Elsevier Science, (1995) Vol 128, 199-230.

[16] Coatanéa, E. et. al., Analysis of the concept of sustainability: definition of conditions for using exergy as uniform environmental metric. *Proceedings of the 13th CIRP International conference on Life Cycle Engineering; LCE2006*, University of Leuwen (2006).

[17] Yue, S. Et al., Application of an integrated CAD/CAE/CAM system for die casting dies. *Journal of Materials Processing Technology*, Elsevier Science, (2003) Vol. 139, p 465-468.
[18] Matrin;L., Moraru, G. And Veron, P., A design-for-casting integrated approach based on rapi simulation and modulus criterion, Ad acta, *International Journal for Product development*, Interscience Enterprises.
[19] Andreasen, M.M. Syntesemetoder på systemgrundlag, PhD-dissertation, Lund University, Lund 1980.
[20] Andreasen, M.M., The Theory of Domains. Technical report, Institute of Engineering design, Technical University of Denmark (1992).
[21] Makkonen, P., Integrated CAD Methodology for Simulation Driven Product Development, OST-95 Conference in Oulu, University of Oulu (1996).
[22] Enqvist et al. Erkka-projekti, http://sovellusprojektit.it.jyu.fi/erkka/. (2002) University of Jyväskylä.