Virtual Prototyping: first practice of a European research group

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Abstract: The EMIRAcle association has been created as a European association in order to refer as a pool of European experts with respect to design and manufacturing scientific research.

A group of EMIRAcle partners have been working on “Virtual Prototyping (VP)” competencies. The long terms main objectives were:

- To set a common understanding concerning virtual prototyping
- To gather competencies in Virtual Prototyping including maturity regarding new concepts and software demonstrators
- To provide to academics or industries methods, models and software to support Virtual Prototyping

The paper aims at presenting first results of that research group concerning the creation of a VP knowledge map (second objective). Those results are based on a design case study led by several partners of the EMIRAcle association.

Keywords: Collaborative virtual prototyping, Life Cycle Analysis, User-centric design, CAPP, DFX

1 Introduction

This research work has been done as “joint research activity” within the European Manufacturing and Innovation Research Association (EMIRAcle). The short and long terms objectives were:

- To map EMIRAcle’s partners competencies concerning virtual prototyping.
- To run a virtual prototyping design case to assess how those competencies are used and how they are expressed in term of design process and product modelling.

- To identify what could be the main issues of European research in the future regarding virtual prototyping. One of the objectives of EMIRAcle is indeed to lead the European research to face the current industrial mutation.

The paper gives the first results to tackle the first and second objectives. The second section of the paper introduces the research context. The third one presents the design case which has been studied. The fourth one gives the results obtained so far and details the analysis model and the software systems used for each expertise that have been participating in the virtual prototyping process. The fifth section presents the analysis of that research work and finally the conclusion gives a synthesis of this work and is followed with some recommendations for further works.

2 Collaborative virtual prototyping: a set of European competencies

2.1 Virtual prototyping: a large field to lead industrial evolution

For 30 years design activity strongly evolved in industry and this change has led to significant “time to market” reduction. This evolution has been strongly focused on product information that should support the entire Product LifeCycle [1-3] taking into account industrialisation, manufacturing, use and end-of-life information in the development phase, design process information and industrial performance have also been studied as presented in [4, 5]. The evolution also concerns computing aided tools to support the design activity and to digitally manage the data models previously introduced. Currently design is fully supported by CAD system to obtain 3D digital models linked to other software to support the whole product lifecycle:

- CAx (i.e. CAD, CAM, CFD, FEA...) systems used to assess product’s behaviours in each phase of its lifecycle.
- PLM systems that provide functionalities to manage product BOMs (e.g. file workflow, access rights, configuration…) in a collaborative design context.
- CSCW software and devices that provide digital support for informal collaboration (e.g. videoconferencing devices, AREL software...).

However, an assessment of current CAx and PLM solutions shows that they are only partly matching with the modelling and methodological concepts proposed as the future trends in engineering design [6]. This computer supported environment is what the authors assume as being *virtual prototyping (VP) or Virtual Product Development*: “how to virtually support the design process, the design solutions and the decision making process regarding to product, manufacturing system, plants...”.

2.2 EMIRAcle: competencies on design, manufacturing to foster innovation

EMIRAcle[1] is an association of 20 leading research laboratories in 14 different countries. Their common mission is to act as a collaboration partner for European Product Development Enterprises in Manufacturing and Innovation research, with the goal of maintaining and improving their leading positions worldwide by increasing their productivity and innovation power. It has taken the unique step of integrating distributed

[1] http://www.vrl-kcip.org/

multinational expertises at a one-stop address that offers a multitude of services, thus providing an opening to the international research community and direct access to the employees of the future. Within that association knowledge map has been set. The paper then presents the use of that knowledge map for Virtual Prototyping.

3 A design study to highlight *VP* EMIRAcle competencies

3.1 Introduction

Beyond the initial established knowledge map, the authors, as member of the EMIRAcle association, initiated a collaborative research work based on VP in order to:

- Really detail the EMIRAcle competencies in the VP field.
  - Those competencies can be related either to conceptual approaches or to information modelling or to CAx and collaborative platform.
  - The level of maturity of those expertises has also to be identified to assess whether the expertise has been validated on small scale examples or whether it has been consolidated on large scale examples.
- Set a real European common understanding in that field of VP.

This work has been deliberately based on a very simple design case in order to avoid mixing both product complexity and collaborative work complexity. Authors decided to base the VP process on a "*jigsaw"*. The first step was then to assess the initial jigsaw's behaviours from the initial prototype and the second step was to propose new solution (i.e. product information including CAD model) with respect to specific experts involved in the VP process (cf. Figure 1).

The research work began in December 2007 and the results presented in that paper have been reached in June 2008. This work should obviously be continued in the very next future within the EMIRAcle association.

3.2 Research process

The research work has been following a bottom-up approach to progressively make each participant work together (cf. Figure 1) to the objectives presented in section 3.1:

- Detailed presentation of each one's expertise: model and document template have been proposed to gather specific information regarding expertises.
  - An IDEFØ model has been used to express what could be the process model of expertises that can be seen as activities in the design process.
  - PowerPoint template to give some more information with respect to concept, model and maturity as requested in the objectives.
- After the presentations, relations have been set among expertises. This analysis have concerned the potential links among input-control-outputs and mechanisms (ICOM) if the IDEFØ activities.
  - Each *ICOM* information used in each IDEFØ activity has been detailed by each partner to understand which could be related to others. Each arrow given on Figure 1 formalises one of those relationship among VP activities.

- Those relationships give some initial indications on the potential future collaborations in the VP process. Section 4.5 gives some potential environment that could be used in collaborative VP activity even it is not detailed in this paper.
- Those relationships also explain how expertises can provide input (first form features coming from conceptual and embodiment design) or control (constraints on the solution space) to CAD modelling activity.

• Finally pools of expertises have been set to gather several partners that were working on the same expertises. The separation into pools has been done with respect to the objective of each expertise and their location in the global product life cycle (cf. pool list below). In that way, common research work and discussion have been fostered (cf. 4). Five pools have, so far, been set related to:

- *Requirements analysis, Conceptual and embodiment design*. That pool is composed of two authors of the project.
- *Life Cycle Analysis (LCA)* is gathering three authors of the papers aiming at tackling LCA.
- *CAPP and manufacturing processes simulation* is related to detailed design phase and tackle by one of the authors.
- *User-Centred Design* is led by one author so far but should interest many more as it is an emergent topic.
- *CSCW and collaborative CAD* pool has been so far created to globally treat IT system aspect needed in VP. Nevertheless it seems obvious to add in the future work some other expertises related to CSCW in order to address the real problem of cooperative work in the global design and decision making process. So far CSCW pool is set as isolated on Figure 1 but is actually resources (i.e. mechanism) for each other activity.

Next section gives a synthesis of the first results in term of VP activity and information modelling. LCA pool is more detailed than the others as it has been more commonly investigated so far.

4 Competencies map: synthesis of the first results

4.1 Requirements analysis, conceptual and embodiment design

As presented in [7], requirements analysis, conceptual and embodiment design are the first phases of engineering design. They have been studied with respect to specific concepts developed in each partner's laboratory.

<u>*Functional analysis and alternative solutions*</u>

APTE[1], FAST[2] and axiomatic design have been implemented on the jigsaw. This approach has been also used to provide alternative solutions based on physical assessment of the product. For instance, one design solution can be based on linear motor [8] instead of rotative one as in classical jigsaws.

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[1] APplication aux Techniques d'Entreprise
[2] Functional Analysis System Technique

Energetic flow analysis toward CAD modelling

As far as conceptual and embodiment phases are concerned, an original DFX approach based on energetic flows analysis has also been proposed. Those new concepts [9] provide a specific product model that links Function, Physical Principles and Technological components (FPPT). In a least commitments way, this FPPT model provides and justifies the minimal CAD features needed for energetic functions (cf. Figure 1). Others CAD features will then be provided to map other functions (e.g. manufacturing, aesthetic functions) in a DFX approach [10].

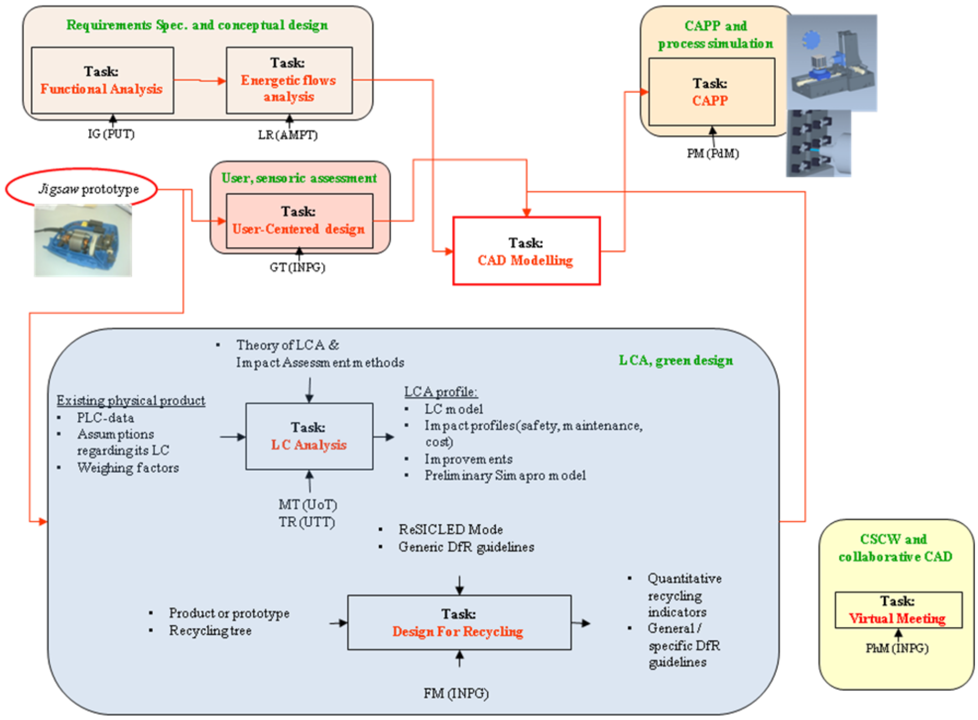

Figure 1: IDEFØ final expertise map with activities, pools

4.2 *Life Cycle Analysis*

Three participants of the research work (MT, TR, FM) have been indeed identified as eco-designers. Those three competencies were kept in the group as they were considered as complementary: indeed two researchers decided to work on Life Cycle Analysis and one researcher on Design for Recycling. Both approaches are presented separately in the next paragraphs and are then discussed commonly in the analysis section.

Life Cycle Analysis (LCA) approach

This work was divided in two stages. The first was the comparison of the LCA results obtained by the University of Twente team (UoT), with Jig- and hand-saws, and the University of Technology of Troyes (UTT) team, which considered Jig-saws with copper and aluminium motors. The second stage was the search for solutions to reduce the environmental impacts of the jig-saw, on the basis of comparative LCA.

The LCA was realized by means of the commercial software Simapro. The UoT and UTT used the Eco-indicator 95 and the Eco-indicator 99 “endpoints” methods, respectively. At this point, it is pertinent to mention that the sets of impacts indicators of these two methods are not completely the same (set of indicators). The evaluation levels used were the European normalization and the single score. Most of the data result from the Ecoinvent database (versions 1 and 2). The research for materials to substitute the copper was realized by means of the CES software.

The LCA methodology of the *jigsaw* was done in the following way: a) The *jigsaw* was totally disassembled to make the lifecycle inventory and each piece was weighted and analyzed, b) the systems studied were simulated through the LCA software and c) the interpretations and the suggestions to improve the jigsaw were based on this result.

The results of UoT show that the hand-saw is less impacting than the jigsaw on most of the 11 studied environmental indicators. In what concerns only the jig-saw, we noticed a significant negative impact on the power-cable as well as on the motor. An analysis of sensibility was realized by substituting primary copper by some recycled copper, which apparently improves the environmental balance of the jig-saw.

UTT analyzed the components of the jigsaw. This work confirmed the reported results from UoT. The wire of the motor, originally in copper, has a very significant impact for the environmental balance of the jigsaw. An analysis done with the CES software allowed the UTT's team to evaluate the substitution of wires in cooper with wires in aluminium. We observed a global improvement of the environmental balance. This substitution of material, however, increases the size of the motor. Consequently, more steel is required not only for the motor, but also to increase the size of the rotor.

The comparative LCA have highlighted on the environmental impacts of the system and suggests that an improvement at the stage of design should limit those impacts.

Design for Recycling (DfR) approach

End-of-life performances of products are gaining in importance in the industry due to societal pressure, legislation (according to EU WEEE Directive, electr(on)ic products should attain 50 to 90% per weigh of recoverability), and to customer expectations. Tomorrow, recoverability performances could also lead to differentiated pricing through lower taxes for better designed products. In order to analyse the ability of the “*jigsaw”* to be recovered at its end-of-life, the ReSICLED [11] and its simplified version EcoDEEE [12] methodologies have been applied to the product under re-design. Indeed, considering several recovery scenarios, it is possible to calculate recoverability indicators, i.e. % of product that could be recycled or energetically recovered at its end-of-life, considering only economically feasible processes. The two scenarios considered for the study were:

- Scenario 1: quick manual depollution + shredding + material sorting + material recycling; this scenario is well spread in the industry as it is quite cheap for quite good performances; however, it implies important losses of materials, problems of materials compatibility; moreover the selectivity (of valuable materials) is low;
- Scenario 2: complete manual disassembly + material recycling; this scenario leads to high selectivity of materials (and therefore to higher recyclability indicators), if cooperation between recyclers and product manufacturers is put into place; however, longer manual dismantling imply higher costs.

The calculation is based on a database of technical, economical and environmental performances of recovery processes developed in the EcoDEEE project. The input data of the calculation are the product architecture and its Bill of Materials. The method is therefore applicable at any time of the design process as soon as these two parameters are known (even roughly). Results of the application of the ReSICLED/EcoDEEE method on the jigsaw design option are given in Table 1.

Table 1. Results of recoverability analysis of a jigsaw design option

	Scenario 1 - Shredding	Scenario 2 - Dismantling	Directive objectives
Recycling (% of weight)	45%	68%	70%
Waste (% of weight)	55%	31,94%	30%
Cost (€/kg of product)	~ -0,1€/kg	~ -0,5€/kg	best price

From this analysis, scenario 2 can be considered as the most efficient from a waste perspective (it is very close from the WEEE Directive objectives), although it is far more expensive than the other. From the analysis, the used method allows the recycling expert to track recyclability loss for both scenarios, i.e. product parameters (e.g. materials, joining techniques, architecture) that are not fully adapted to the recovery scenarios, and to identify recovery-sound redesign opportunities.

4.3 Computer Aided Process Planning and simulation

Modifications in the shape or in the geometric features usually entail changes also in the machining process to obtain them. In some cases, changes can be moderate enough not to interest the manufacturing system configuration; in other cases, product modifications have an impact also on the manufacturing system [15]. In this work the concept of manufacturing system embraces all the production resources different from products; in particular, regarding the field of metal cutting processes by means of CNC machining centres, the main system entities are represented by the machines and the equipments used for clamping raw parts.

The Redesign of clamping equipments is a time-consuming activity to be potentially repeated for every restyling of the product. In the following a method to rapidly check the real need for this is presented. The method makes use of a CAD/CAM system and a machining simulation software:

- Feature recognition, pallet configuration and machining simulation (cf. Figure 1)
- The simulation gives as output a feedback on collisions that may have happened between the moving elements of the virtual machine and the solid models of the pallet,
- If no errors are reported, the process plan is completed.
- Product features are therefore characterized not only by their geometrical data, but also by process-related information, such as the G-code instructions that allow a CNC machine tool to realize them.

STEP-NC compliant way of storing data generated with CAM tools allows to save time in maintaining and upgrading process-related information during the whole product lifecycle.

4.4 User-Centred Design

One of the cornerstones theories about user involvement is User-Centred Design (UCD). UCD as a design approach was the first time introduced in the standard ISO 13407: Human-Centred Design Processes for Interactive Systems [13]. The main issue is how to involve and integrate the user in the design process. The main idea of Jokela's new UCD process model is to inter communicate the user with the usability in cycling process [14]. Another important issue in UCD is how identifying and selecting relevant users in the development work. In practice it is commonly possible to involve only a limited number of users, and therefore it is very important how to select the "representative users" to centre the design on their requirements and expectations. There are several studies in different themes.

From the "*jigsaw"* analyses, a panel of users has been put in situation with the first prototype of the jigsaw. Thus, five users tried the device with the support of a scenario written to evaluate specific design functions. For better results, the jigsaw was manipulated in real condition in the users' environment. Videos, audio recording, photos and remarks have been taken during all the manipulations.

After analysing all the experiments outcomes, it is possible to propose modifications to the designers: ergonomics factors, more professionals' functions in use (less vibration, laser trajectory prediction, etc.) or better adapted facilities.

4.5 CSCW and collaborative CAD

Apart of asynchronous information and data exchanges through e-mail and documents repository, the collaborative sessions, mainly distant synchronous meetings involving several partners from different countries, have been held trough two kinds of communication environments.

The first and most used communication tool is video conferencing, via H323 (IP addressing) or ISDN protocol. Each partner has at one's disposal a videoconference device, which allows high-quality video and audio communication, together with computer display broadcasting. The audio-video full-duplex feature is currently used for standard meetings, where interactive verbal exchanges are expected. Graphics resolution of the remote display facility is quite good but a very low frame rate does not allow fast animation, and is therefore limited to quite static slide show presentations. This kind of communication tool clearly fits the needs of planned meetings, with a number of participants, and organised either as a design review with one presenter at a time, or as a discussion meeting with a medium level of interactivity and no remote graphic display.

The second communication tool (i.e. collaboration tool) that has been used is the Arel Spotlight™ Application. The Arel client software does not need specific device, except PC, webcam and microphone, and connects through Internet to the Arel Spotlight server that can also host a number of participants in a virtual meeting, with medium quality for video and audio communication, and a high resolution and high frame rate screen sharing facility. This tool is therefore more suited to high interactive meeting, where technical information is to be discussed, around application sharing (even 3D graphics Computer Aided Design tools) or collaborative dialog around screen capture annotation process. That is why Arel communication environment has been chosen to manage technical discussions when interactive software manipulation where needed, around intermediary objects like data sheets sharing or the jigsaw CAD model.

5 Results analysis

The main results of that design study is now discussed in two ways:

- How this map of common expertises can foster innovation in a design (or re-design) process
- How this map of common expertises can open issues for the future of research

This discussion is so far based on Life Cycle Analysis pool as it has been the more detailed one. The other VP activities identified on figure 1 have not been consolidated and commonly discussed in the other pools to reach such analysis. Nevertheless it should be done in the future to reach a common European point of view.

Considering that both LCA and DfR approaches are complimentary (and can also be antagonists), environmental experts organised a virtual meeting to discuss their re-design guidelines (cf. Table 2) in order to present to other members of the design team a coherent environmental view. Redesign guidelines are classified below according to two categories: refine of the design / radical change of the design.

Table 2. Examples of re-design guidelines suggested by the environmental experts

Part of the product	Refine of the design	Radical change of the design
Cable	- "Choose a re-usable / dismantlable cable" - "Work with suppliers to replace virgin Cu by recycled Cu in cable and motor"	- "Look for cable without Cu" (technological solution to be identified) - "Adopt so-called 3D Technology for cable"
Casing	- "Prefer ABS or HIPS for protection hood" - "Avoid stick on left casing" "Choose PP-GF30 (or PP) instead of PA66-GF30"	- "Choose renewable polymers for casing" (tests to be made) - "Turn the metallic parts (stainless steel sole and Cu motor) easily/quickly extractable from the rest of the jigsaw".
Motor		- "Select another type of motor (less heavy in Cu) giving the same output"

This common work done by the environmental team also suggests various research perspectives. The suggestions for the design of the Jigsaw are based on two strategies for product innovation: radical and incremental innovation. The LCA of the jigsaw also raised questions concerning the completeness of the databases, the relevance of inventory stage, the uncertainties of the results obtained with the different methods employed for the calculations, the knowledge capitalization to aid multi-functional design, etc.

6 Conclusion and further work

This work has been led within a European association. The way of working has been collaborative in order to really tackle the problem at a European level and not only in each isolated laboratories. This approach that could provide a European common understanding and solutions to VP issue is indeed much more hard to run and to lead but is a very interesting exercise and goal inside the EMIRAcle association faced to the evolution of the international industrial market.

The first results presented in this paper show the huge perspectives of the work that in the short term could be to extend the analysis to other pool of the other expertises already identified and to provide the whole result of the design case.

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